FINAL REPORT

DEMONSTRATION & TESTING OF ClimaStat® FOR IMPROVED DX AIR-CONDITIONING EFFICIENCY

ESTCP Project EW-201144

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14. ABSTRACT

Patented ClimaStat technology was demonstrated on commercial unitary air-conditioning equipment at two military installations – Marine Corps Air Station, Beaufort, SC, and Cape Canaveral Air Force Station, FL. Energy use of the demonstration equipment is compared before (baseline) and after ClimaStat installation, and energy & cost savings are presented.

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List of Acronyms

45CES/CEL – 45th Civil Engineering Squadron, Cape Engineering Flight
AFSPC – Air force Space Command
ASHRAE – American Society of Heating, Refrigerating, and Air-Conditioning
CCAFS- Cape Canaveral Air Force Station
COP – Coefficient of Performance
DDC – Direct Digital Control
DoD – Department of Defense
DOE – Department of Energy
DX – Direct Expansion
EER – Energy Efficiency Ratio, single condition Btuh/Watt
EMCS – Energy Management and Control System
ESTCP – Environmental Security Technology Certification Program
HVAC – Heating, Ventilation, and Air-Conditioning
IEER – Integrated Energy Efficiency Ratio, weighted average, Btuh/Watt
IOMS – Infrastructure & Operations Maintenance Services
MCASB – Marine Corps Air Station Beaufort
NOTU – Naval Ordnance Test Unit
ORNL – Oak Ridge National Laboratory
SHR – Sensible Heat Ratio

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EXECUTIVE SUMMARY

Military installations utilize unitary HVAC systems for space conditioning in buildings such as commissaries, schools, and theaters, and in portable environment control units (ECUs) to support mobile and battle field operations. The results of ClimaStat field tests demonstrate a substantial increase in Integrated Energy Efficiency Ratio (IEER), relative to conventional HVAC unit baseline performance, along with greatly increased dehumidification capability and reduced energy consumption.

Rigorously instrumented demonstrations of two dual-compressor unitary systems were completed at the Marine Corps Air Station - Beaufort, South Carolina (MCASB) and at Cape Canaveral Air Force Station (CCAFS), Florida. The MCASB demonstration was a retrofit of ClimaStat to a 20-ton unit installed in 2003. The CCAFS demonstration was a new 8-ton unit with humidity control, to which ClimaStat was added after collecting baseline operation data.

ClimaStat reduced energy consumption by an average of 21% relative to the baseline equipment. The technology also enhanced the capability of the equipment to meet dehumidification needs independent of sensible load. In addition, compressor operation was significantly cooler with ClimaStat technology installed, which likely results in longer compressor life as well as sustainability of improved efficiency: compressor temperature averaged 57 degrees-F cooler with ClimaStat. A thorough life-cycle cost analysis shows a payback period of 2.6 years (new unit) to 4.0 years (field retrofit). Incremental cost ranges from 20% to factory-equip a new 8-ton unit with ClimaStat to 50% of the cost of a new unit for refurbishment / retrofit of an existing 20-ton unit. ClimaStat cost per ton drops significantly as system size increases for example, the cost per ton for retrofit of a 20-ton unit is about one-third that of a 5-ton unit.

Current energy efficiency ratings for new air conditioners establish Integrated Energy Efficiency Ratio (IEER) minimums of 9.6 to 12.3, depending on system capacity. IEER is a rating adopted for commercial air conditioning equipment manufactured after January 1, 2010.[1] IEER takes into account changing loads over the course of a cooling season. A companion rating is the Energy Efficiency Ratio (EER). EER is a single point rating for full cooling load at 95F ambient temperature with minimums of 9.5 to 11.5 depending on system capacity.

Two types of comparisons were made: (1) ClimaStat measured IEER versus factory rating, and (2) ClimaStat measured IEER versus measured baselines. The range of improvement stems from whether the equipment modification was a retrofit of an existing air-conditioner unit, or an add-on to new unit; both scenarios were demonstrated. The percent improvement is also affected by the cooling load characteristics of conditioned space and the condition of the existing unit.

ENERGY EFFICIENCY INCREASE OVER FACTORY RATING				
Site	MCASB, South Carolina		CCAFS, Florida	
Rating	IEER	EER	IEER	EER
Rating Increase	**20%**	**10%**	**17%**	**18%**

[1] Air-conditioning, Heating, & Refrigeration Institute (AHRI) Standard 365, *2009 Standard for Performance Rating of Commercial and Industrial Unitary Air-Conditioning Condensing Units*, http://www.ahrinet.org/App_Content/ahri/files/AHRI%20Standard%20365%20%28I-P%29.pdf

ENERGY CONSUMPTION RELATIVE TO BASELINE MEASUREMENT				
Site	MCASB, South Carolina		CCAFS, Florida	
Season	Summer	Shoulder	Humid	Dry
Energy Reduction	**46%**	**40%**	**24%**	**19%**

At MCASB the ClimaStat-fitted unit efficiency is 20% improved over the standard unit factory rating from IEER 11.2 to IEER 13.4. The peak load EER is 10% improved over the standard unit from 10.6 to 11.7. The measured IEER improvement between the refurbished baseline unit and the ClimaStat retrofitted unit is 29%, and the improvement between the "as found" unit and the refurbished, ClimaStat retrofitted unit is a 72% improvement in energy efficiency. ClimaStat showed a 43% reduction in annual energy use relative to the baseline.

At CCAFS there was a substantial reduction in the reheat energy needed for dehumidification accounting for 20% of baseline system energy use, nearly eliminating the need for electric reheat. While providing this reheat energy savings, the ClimaStat unit also showed a 27% increase in cooling energy efficiency during humid-season operation, and a 24% reduction in annual energy use relative to the baseline. The ClimaStat-fitted unit efficiency is 17% improved over the standard unit from IEER 12.5 to IEER 14.7. The peak load EER is 18% improved over the standard unit from 11.3 to 13.3.

Indoor air quality was compared pre- and post- implementation of ClimaStat technology using multiple criteria addressing temperature, humidity, carbon-dioxide, and comfort. Ventilation was acceptable according to ASHRAE Standard 62 defined CO_2 level 100% of the time at both sites. Dissatisfaction with comfort level was less than 1% of the time: 0.5% warm and 0.4% cool.

Upon completion of the respective demonstration projects, the host facilities were approached about their interest in keeping the modified HVAC units in operation or, alternatively, returning the units to their pre-demonstration condition. At both demonstration facilities, the hosts indicated they wanted to keep the ClimaStat technology in place. In fact, the MCASB hosts have expressed an interest in installing ClimaStat on all ten new, replacement A/C equipment on Building 1283.

> Mr. Neil Tisdale, Utilities Director/Energy Manager at MCASB, gave this feedback on the ClimaStat demonstration in January 2013: "The MCCS Maintenance Director is happy with the performance of the unit due to the fact that he has had no complaints. In the maintenance world no complaints is considered a job well done!"

The CCAFS hosts are interested in ClimaStat for nine DX systems serving buildings with tight temperature and humidity control requirements. In addition, Andrews Air Force Base, MD has requested a proposal to provide six new ClimaStat units at EER 14. The results of the demonstration are summarized in two technical papers [to be] presented at the ASHRAE annual meeting on June 23-24, 2013 in Denver, CO. The first paper addresses the theoretical modeling and analysis, the second presents the field demonstration results.

1 INTRODUCTION

1.1 BACKGROUND

Commercial unitary HVAC systems are estimated to consume 0.74 quads of energy annually, or about 54% of commercial building cooling primary energy consumption, and are used to cool about 50% of all commercial space.[2] Military installations utilize unitary HVAC systems for space conditioning in buildings such as commissaries, schools, and theaters, and in field cooling systems used for mobile operations. ClimaStat is a new technology which, when added to existing or new unitary HVAC systems, can significantly improve energy efficiency and dehumidification capacity. Advantek Consulting developed and patented the new technology which, when installed on conventional unitary HVAC systems of all sizes, will significantly reduce energy usage and improve dehumidification performance. The technology is based on a new paradigm for control of major elements of unitary HVAC equipment, including refrigerant management, compressor, cooling coil, and supply air fan. ClimaStat utilizes readily available and serviceable components that can be optimized for specific cooling performance objectives, such as satisfying the actual sensible-to-latent ratio. The results of ClimaStat lab & field tests have demonstrated a 15 – 30% increase in Energy Efficiency Ratio (EER), relative to conventional HVAC unit baseline performance.

Unitary DX split-system and package air conditioners are ubiquitous in DoD facilities and mobile units. The large potential for improvement makes unitary systems an outstanding target for DoD facility energy efficiency upgrades. The energy efficiency of current unitary HVAC systems is much less than that of distributed chilled water systems and few cost-effective choices exist for increasing their energy efficiency (1). Although DoD facilities utilize central chilled/hot water plants for large building heating and cooling, facilities such as commissaries, base exchanges, theaters and schools are often located away from distribution networks and are therefore served by stand-alone unitary-DX HVAC systems.

Unitary HVAC systems are readily available in a range of capacities from 5 to 100-tons, have a relatively low first cost, and are easily serviced. However, even best-in-class EER-14 commercial unitary[3] equipment do not give the 30% increase in efficiency over ASHRAE Standard 90.1 desired to meet federal energy reduction goals. Current energy efficiency specifications for new unitary air conditioning and heat pump systems[4] establish EERs of 9.7 to 14.0, depending on system capacity. However, the substantial base of installed unitary systems has an EER of 9.0 or less, dependent on system condition and maintenance history.[5]

For DoD facilities located in hot & humid climates, such as the two proposed demonstration sites, control of relative humidity (RH) and indoor air quality (IAQ) in conditioned spaces is

[2] AD Little "Energy Consumption Characteristics of Commercial Building HVAC Systems – Volume 1: Chillers, Refrigerant Compressors, and Heating Systems" 2001.

[3] Commercial unitary equipment is understood to mean equipment over 5 tons capacity utilizing 3-phase electric power. EER-14 means an Energy Efficiency Rating of 14 Btuh of cooling per Watt of electric usage.

[4] The Consortium for Energy Efficiency (CEE), a North American non-profit organization with members including utilities, state energy offices, research organizations, and environmental groups, developed specifications for unitary systems – see http://www.cee1.org/com/hecac/hecac-tiers.pdf (2)

[5] *Efficiency Maine* suggests assuming EER of 9.0 for systems 5-10 years old and 8.0 for systems 10-15 years old - http://www.efficiencymaine.com/pdfs/EM_SAW_Rooftop.pdf

often less than satisfactory with unitary A/C systems because of relatively warm coil leaving air temperatures and frequent compressor cycling. Their limited dehumidification capability results in a limit on the amount of fresh outside air a unit can condition of about 20% of the total airflow, with the remaining 80% being re-circulated air. Insufficient fresh air and high humidity can be a problem for occupants since it is causative to impaired productivity and increased transmission of viruses and bacteria. Allowing indoor RH to rise above an average of 60%$_{rh}$ or a peak of 70%$_{rh}$ can cause indoor air quality problems from mold growth and associated respiratory irritants and odors in the conditioned space. Lack of RH control is particularly problematic in spaces with a large variability in number of occupants, such as classrooms, meeting rooms, commissaries and auditoriums. If outside air is provided commensurate with occupancy,[6] RH control is even more difficult in hot & humid climates because outside air is a major source of water vapor.

These problems are the result of relatively warm coil-leaving air temperatures, frequent compressor cycling, and airflow limitations; as coil leaving air temperature increases, dehumidification decreases (2). Most package unit cooling coils are thin (only two or three rows of refrigerant tubing deep) and coil air velocities are relatively high (over 400 fpm); manufacturers do this to reduce materials cost and increase energy efficiency ratings. This design results in warmer coil-leaving air temperatures, because of less than optimal heat exchange contact time and surface area. Cycling occurs because most compressors have two operating modes: *on* or *off*; when the thermostat is satisfied the compressor abruptly cycles off. Even the latest digital scroll compressor technology is not continuously variable. With the compressor cycled off, the condensed humidity on the coil evaporates back into the airstream as the coil warms, and space relative humidity rises. Larger package units have dual-stage compressors so that the first stage compressor does not cycle as often, and can run continuously on design days. Yet most units have only a single fan speed, so package units equipped with intertwined-circuited cooling coils experience warm coil-leaving air temperatures up to 64°F (rather than the standard 55°F) and have essentially no dehumidification capability at part-load[7]. Units with multiple fan speeds or variable air volume can overcome the temperature problem with special control programming, but then suffer from deficient fresh air intake at lower fan speeds.

1.2 OBJECTIVE OF THE DEMONSTRATION

The overarching performance objective of the ClimaStat demonstrations at MCASB and PAFB are to appreciably increase the energy efficiency and reduce the energy consumption of the optimized unitary DX equipment. Project objectives are to demonstrate in DoD buildings (1) the life-cycle cost benefits of ClimaStat technology in both retrofit of previously installed and modification of new unitary HVAC systems; and (2) demonstrate and document energy savings of at least 15% along with significant indoor air quality improvements resulting from ClimaStat technology compared with current equipment. The objectives for each demonstration site are:

[6] ASHRAE Standard 62.1-2007, *Ventilation for Acceptable Indoor Air Quality.*

[7] Coil entering air at 78°F / 60%$_{rh}$ has a dew point of 63°Fdp, so there will be no condensation when this air is cooled to 64°F thus no dehumidification occurs.

Marine Corps Air Station Beaufort, SC – Address the project objectives for a typical retrofit of ClimaStat to existing unitary A/C units, and conduct LCC analysis based on remaining life of unit being modified. Evaluate improved dehumidification performance resulting from ClimaStat retrofit.

Patrick Air Force Base, FL – Address project objectives for a replacement (i.e., new) unitary packaged A/C unit with ClimaStat add-on occurring prior to unit installation at Patrick. LCC analysis will be based on comparison with comparable unit without ClimaStat.

1.3 POLICY DRIVERS

- Installations Energy Instruction DODI 4170.11
- Energy Policy Act of 1992
- Energy Policy Act of 2005
- Executive Order 13123
- Executive Order 13423

2 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

ClimaStat is a refrigeration-science technology that has been tested and proven at the bench scale, lab and field prototype stages, and is primed for widespread demonstration and commercialization. It can be factory installed in new equipment as well as field-retrofitted to existing equipment. The technology involves modifications to a DX system that result in more precise control of supply air over system evaporator coils, along with optimized refrigerant management, resulting in lower pressure differentials at compressors. Figure 2.1 shows the major component of ClimaStat added to a conventional unitary AC system, a liquid-suction heat exchanger/accumulator. Testing shows that ClimaStat provides a 15 to 30% improvement in system EER; reduction in compressor run hours; improved dehumidification of supply air; and increased outside air ventilation to the occupied space, if desired, without adverse effects on hardware reliability.

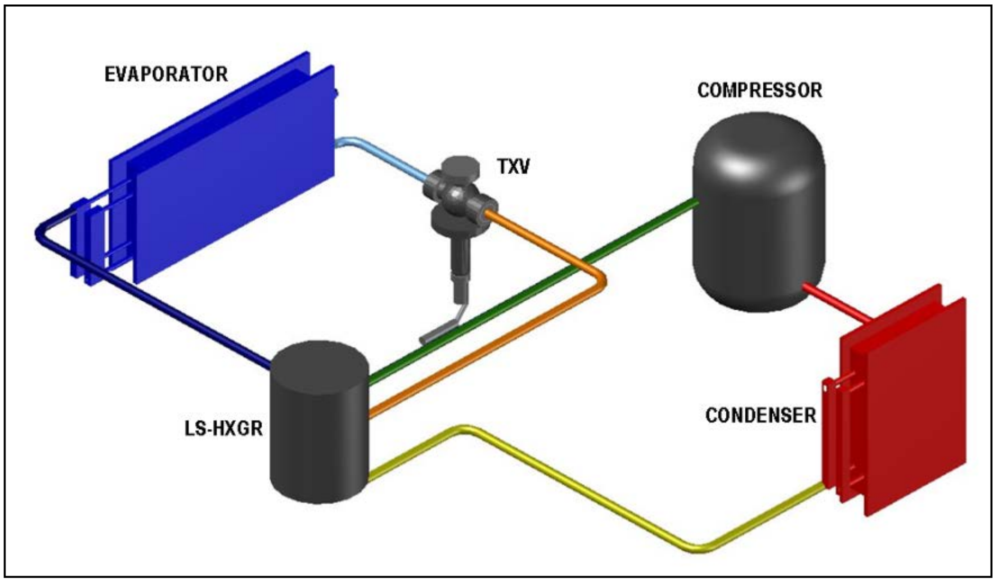

Figure 2.1-1 ClimaStat refrigeration circuit component layout.

ClimaStat advances unitary system technology by responding to varying latent (moisture) loads in addition to conventional sensible (temperature) load control. Under this novel approach, energy efficiency is raised by increasing cooling coil velocity under most conditions, while reducing coil velocity when dehumidification is needed. In comparison, current standard unitary equipment cannot control the proportion of sensible and latent cooling; latent loads can only float and only sensible load is controlled. ClimaStat components address this problem with an optimized cooling coil mated with relatively simple, readily available parts from the food and industrial refrigeration industry, which are reliable, proven, easily maintainable, and low cost.

The root basis of the increase in energy efficiency achieved by ClimaStat is reducing refrigerant differential pressure requirement and increasing capacity.

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It is well known amongst refrigeration engineers that compressor capacity increases as the refrigerant pressure differential it must work against decreases. ClimaStat obtains efficiency gains by minimizing this pressure differential across the full operating regime. It thereby maximizes compressor capacity, which means more cooling capacity. Also, compressor power input decreases as the pressure differential decreases. So ClimaStat correspondingly reduces compressor power input. Increased capacity and reduced power input both contribute to ClimaStat's higher energy efficiency and reduced energy consumption.

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ClimaStat is a fully developed technology ready for demonstration. Technology development stages prerequisite to demonstration have been successfully completed. Refinement and testing of an engineering prototype culminated in issuance of US Patent 6,427,454 in 2002. Then, development, testing and refinement of a production prototype, funded in 2003 under DOE project DE-FG36-03GO13003 with support from Carrier Corporation, were completed in 2006. More recently, initial field tests on four Trane (American Standard) systems at a university site were concluded in 2009.

A production prototype was constructed based on a high-efficiency R-410a Carrier Centurion roof top package unit. Performance testing under standardized laboratory conditions confirmed advantages and facilitated comparison with competing technologies – see Table 2.1-1. Test data

[8] A near-azeotropic mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (C_2HF_5, called R-125)
[9] Chlorodifluoromethane, a hydrochlorofluorocarbon that is considered harmful to Earth's ozone layer and is also considered to be a greenhouse gas.

was analyzed to identify refinements, which were implemented to further improve performance in an iterative procedure that resulted in a nearly optimized technology achieving an improvement of 11% in EER and a 7% reduction in compressor run time along with significantly improved dehumidification, giving a 18% reduction in energy consumption. Field test data from four Trane Voyager rooftop package units at a university site show an overall 18.7% improvement in operating EER and a 16.5% reduction in energy consumption with an equal level of dehumidification. These prototypes were constructed using readily available, standard air-conditioning components.

Cooling Performance Entering Air 73F / 65wb in units of Tons (12,000 Btuh)
Carrier Centurion Model 48PG-06 with ClimaStat - Lab Test Results

	SENSIBLE	LATENT	TOTAL	SHR	EER	LHR	Watts
Standard Unit 2500cfm	3.8	1.8	5.6	0.67	13.6	0.33	4949
100% Coil Air	4.2	1.4	5.6	0.75	15.1	0.40	4555
Mix Coil and Return	3.1	2.1	5.2	0.60	13.8	0.29	4475

Increase in Dehumidification Capacity:	15%
Increase in Energy Efficiency Ratio:	11%

Table 2.1-1 Previous ClimaStat test results.

Additional engineering analysis is desirable to increase the accuracy of savings predictions and implementation cost estimates under various field retrofit and factory installation scenarios. Critical field maintenance and support needs have been identified and addressed as detailed in Section 5.5. Testing and refinement of the control hardware and sequence of operation for suitability for field demonstrations is underway. Advantek completed the required analysis and design work for the demonstrations five months.

Two military installations participated in the proposed ClimaStat demonstration, the Marine Corps Air Station (MCAS) Beaufort in South Carolina, and Patrick Air Force Base at Cape Canaveral, Florida.

2.2 ADVANTAGES & LIMITATIONS OF THE TECHNOLOGY

2.2.1 Advantages of ClimaStat Technology

Every U.S. military installation is expected to have unitary HVAC equipment installed on buildings, and ClimaStat can added to all this equipment and also to mobile HVAC equipment used for field operations. ClimaStat will use the same refrigerant used in the equipment being modified and the environmental impact of adding ClimaStat to conventional unitary equipment should be minimal, if good refrigerant management is practiced.

The carbon footprint associated with ClimaStat-equipped HVAC is less than conventional unitary equipment, due to the reduction in use of grid-delivered electricity. The Energy Information Administration estimates that CO_2 emission reduction for both demonstration sites (in the South Atlantic Census Division) was 1.34 lb/kWh, based on 1999 data[10]. At this rate, the MCASB demonstration unit should reduce CO_2 emissions by 8.7 tons/yr, and the Patrick AFB

[10] U.S. Dept. of Energy, Energy Information Administration, *Carbon Dioxide Emissions from the Generation of Electric Power in the United States*, July 2000, Table 4.

demonstration unit should reduce CO_2 by 5.1 tons/yr. If DoD chooses to adopt ClimaStat technology on both new and existing unitary HVAC equipment, it can significantly reduce greenhouse gas emissions associated with electricity purchased by all services.

The combination of increased energy efficiency, along with superior humidity control and fresh air ventilation, for DX air-conditioning units in both stationary and mobile applications offers DoD a technology that helps meet goals of multiple missions (12, 13). Substantial reduction of energy use by unitary HVAC systems in DoD buildings is the primary benefit. Additional benefits are longer HVAC compressor life due to reduced refrigerant pressure differential and reduced operating hours. Energy use reductions of up to 60% can be realized in systems utilizing reheat for humidity or temperature control.

ClimaStat technology is well suited to DoD Performance Contracting efforts to reduce facility operating costs. The proposed demonstration of ClimaStat technology, both as a retrofit to existing unitary systems and as an enhancement to new equipment, will provide a solid basis for technology deployment at all DoD facilities with unitary DX equipment and significant cooling loads. The extent of economic benefit of performance improvements depends on the following three factors:

1. *EER of retrofit vs. new OEM equipment*: The Energy Efficiency Ratio (EER) of currently installed unitary DX equipment is typically a bit lower than new equipment of similar capacity. We have assumed an in-service unitary system, such as those we plan to retrofit with ClimaStat, has an EER of 9.0 to 10.1, dependent on equipment age and condition[11]. A new standard of EER 11.0 has been proposed to the U.S. Department of Energy (DOE) during rule-making on energy efficiency standards for commercial unitary DX equipment, with a recommended adoption date of January 1, 2010. However, this new standard has not yet been adopted, so new unitary systems are assumed to have an EER of 10.1, based on DOE guidance.[12] For purposes of the BLCC analyses below, we assumed an EER of 9.1 for identified air conditioning units at MCAS Beaufort and Patrick AFB. We assumed an EER of 10.1 for new units that will replace the existing units at the end of their service lives.

2. *Capital cost of retrofit vs. new OEM equipment*: Retrofit of existing unitary equipment is assumed to have a capital cost of $380 per ton of capacity, while adding ClimaStat to new unitary equipment is assumed to have a capital cost of $112 per ton of capacity.[13] The difference in cost stems from the design and installation work necessary for field retrofit of existing equipment, while a factory-installed ClimaStat system would be a repeatable design and installation of components that are commonly used in unitary DX manufacture. For comparison, the cost of replacement equipment averages $620 per ton plus about $400 per ton for installation – a total replacement cost of around $1,000 per ton. ClimaStat cost per

[11] *Efficiency Maine* suggests assuming EER of 9.0 for systems 5-10 years old and 8.0 for systems 10-15 years old - http://www.efficiencymaine.com/docs/at_work/EMBP16176_SAW_Rooftop.pdf Comparative central plant based systems have EER of 7 for older air-cooled equipment to EER of 20 for the latest high-efficiency variable speed systems.

[12] *Recovery Act: Advanced Energy Efficient Building Technologies,* Funding Opportunity Number DE-FOA-0000115, U.S. Dept. of Energy, issued 6/29/2009, Attachment A "Guide for Evaluation of Energy Savings Potential," Table D.

[13] Advantek cost estimates for proposal in response to DE-FOA-0000115.

ton drops significantly as system size increases for example, the cost per ton for retrofit of a 20-ton unit is about one-third that of a 5-ton unit. Also, electric utilities may provide incentives for purchase of new equipment that is significantly more efficient than standard equipment. For example, the Pepco Industrial & Commercial Energy Efficiency Incentive Program offers incentives of $35 - $70/ton of capacity for new unitary high-EER HVAC units.[14] For the purposes of the demonstration, no utility incentives are assumed.

3. *Ratio of sensible and latent cooling loads*: Both of the demonstration sites are in the hot & humid climate zone, so the latent load for dehumidification is a relatively large portion of the total cooling load (latent plus sensible loads equals the total cooling load). In arid climates where humidity control is not as important and nearly the entire load is sensible, ClimaStat will provide even greater energy efficiency improvement than a comparable system in a hot & humid climate. ClimaStat adds a humidity response function and provides improved comfort in the conditioned space. Existing unitary equipment does not compensate for increased latent loads during periods of lower sensible loads, and this can result in buildup of space relative humidity. For example, in the MCAS Beaufort Base Exchange building, the 20-ton demonstration unit utilizes two compressors for energy efficiency. At partial sensible load operation, one compressor is taken offline by the thermostat control, while the full evaporator coil is still used for cooling. As a result, discharge temperature from the evaporator coil increases and dehumidification capacity is decreased, resulting in unacceptable relative humidity levels in the conditioned space. The ClimaStat retrofit to this unit provides greater dehumidification during periods of lower sensible loads. The economic benefit of improved humidity control is estimated by assuming ClimaStat replaces the standard factory hot-gas reheat option for unitary systems. For example, Trane offers a humidity control option on its new unitary equipment that adds $1,500 to the cost of a 20-ton unit, and increases electric energy use with attendant greenhouse gas production.

	Simple Payback (years)	Savings to Investment Ratio (SIR)	Adjusted Internal Rate of Return (AIRR)
MCASB retrofit – 10 yr	4.04	2.17	11.33%
MCASB retrofit – 20 yr	4.04	3.79	10.10%
Patrick AFB – 10 yr	2.63	3.31	16.11%
Patrick AFB – 20 yr	2.63	5.78	12.44%

Table 2.2-1 Demonstration Cost/Benefit Estimates for ClimaStat installations.

The economic benefit of energy savings associated with the ClimaStat demonstrations at the MCASB and PAFB was calculated using BLCC 5.3 software, with the Milcon: ECIP template. Payback period was calculated to be 2.63 years for PAFB and 4.04 years for MACSB. Each project is evaluated by generating BLCC reports for 10 years and 20 years. BLCC results are presented in Table 2.2-1 and detailed output is in the Appendices.

[14] https://cienergyefficiency.pepco.com/Documents/Pepco%20HVAC%20Form.pdf, “Unitary HVAC Incentives Application”, 09/04/2009 v2.

2.2.2 Limitations & Risks of ClimaStat Technology

Based on prior ClimaStat field test experience technical risks are small. The risk of not meeting technical performance expectations is low. Nearly all risks with engineered factory installations have been identified and solved. The primary concern in the proposed demonstration is to prevent excessive / run-away coil freezing. Freezing is a concern with any DX system, so proven methods exist to prevent it. ClimaStat performs best at the lowest possible evaporator coil temperature, which theoretically is just above the freezing point (32°F). Light frost on the coil is acceptable and even enhances performance; however, once frost turns to solid ice and begins to insulate the cooling coil from the airstream, the ice layer builds thickness and cannot thaw unless the compressor is cycled off for a period of time.

In closely watched tests, Advantek can intermittently operate the coil as cold as 28 ~ 29°F, and set the damper adjustment to cycle above the freezing point to allow the coil to thaw, giving an average coil temperature of about 30°F. In these tests, the equipment has a variable modulating damper with a controller and a coil temperature sensor, and the controller is set to the desired temperature (say, 29°F) and allowed to cycle. This approach works flawlessly and reliably for short-term tests.

In operating field installations, there are four factors that need to be addressed:

1. Excessive filter pressure drop due to overloaded filters that are not replaced by maintenance staff possibly could reduce airflow low enough to allow coil freezing.
2. As the outdoor ambient temperature drops, so does the cooling coil entering air temperature and the condensing temperature. This results in a reduced cooling coil temperature, which possibly could drop below 32°F for a period of time long enough to allow ice to build.
3. To keep cost low, a simple two-position open/closed damper could be used and eliminate the coil temperature sensor, which reduces the level of control as well.
4. Multiple compressor units can over-cool as additional stages are energized when the bypass damper is open.

These factors have been successfully addressed by (1) stressing the importance of regular filter changes and proper airflow settings, (2) using a coil temperature control dead-band with a slightly higher setpoint, such as 35°F rather than 32°F to provide a safety factor, (3) installing additional sensors such as a filter differential pressure sensor to alert staff that filters are overloaded, and an evaporator coil temperature sensor, and (4) using additional controls such as a modulating damper or variable fan speed to maintain a minimum coil temperature, and a higher-stage compressor lockout so that only one compressor operates when the damper is open. Some or all of these measures have proven sufficient to prevent coil freezing under a wide range of field conditions.

Two issues of concern with field-retrofits in general remain, but these can be straightforwardly managed. First, as with any field retrofit, improvement can be somewhat unit specific and depends to some degree on existing conditions. Variability can be managed with screening to identify potential system candidates, along with prediction of potential energy savings. For example, tests show ClimaStat will provide greater EER improvement with 2-compressor intertwined coil units (e.g. *Trane Voyager*) than with 4-compressor face-split coil units (e.g. *Lennox Strategos*). Second, field retrofit costs can be higher than factory installations early in

the learning curve at low quantities. Retrofit costs will be managed by employing trained experienced installation technicians.
Release of refrigerant during a field retrofit is a possibility that will be addressed through diligent onsite refrigerant management, including careful evacuation, collection & reuse of refrigerant when the system is opened for service. For example, a LEED-EB best practice is to limit refrigerant release to less than 3% of total charge per year, and less than 25% over the remaining service life of the HVAC equipment. Refrigerant recovery and recycling has a well-known protocol with HVAC service providers, and this element has been stressed during the ClimaStat demonstrations.

2.2.3 Maintenance Personnel Training

Training sessions were conducted at MCASB and CCAFS to inform facilities & maintenance staff about ClimaStat technology. The new components were found to be easily understood and the sessions lasted less than 1 hour including hands-on explanation, with no unresolved concerns at either demonstration site. The facilities directors were provided with an O&M Manual and a copy was placed inside the air-conditioner units for ready access by service personnel.

From the perspective of a technician servicing a unit equipped with ClimaStat technology, the unit appears internally to differ very little from a standard factory unit. The new components of interest are the liquid-suction heat exchanger accumulator (LSHXA), the damper bypass and actuator, the liquid-line sight glass, and the blower variable speed drive. Of these, only the LSHXA is typically unfamiliar to service personnel; the other components are found in a variety of other types of HVAC equipment; their maintenance needs are well known so little explanation is required other than their intended mode of operation, settings, and for the actuator and drive, control connections.

The only service action that differs markedly between a ClimaStat unit and a standard factory unit is checking and adjusting the refrigerant charge. The charge level on a standard unit is determined by measuring either degrees of liquid-line subcooling *or* degrees of suction-line superheat, and the ambient temperature, and comparing these values to a chart or table in the factory service manual, or posted on or in the unit, along with high-side pressure. The charge level on a ClimaStat unit is assessed by measuring both the liquid-line subcooling *and* the suction-line superheat, while keeping an eye on the sight glass and monitoring the high-side pressure – no more complex but there are subtle differences that the experienced Trane technician at MCASB was quick to become skilled at once he understood the intended operating point.

3 PERFORMANCE

3.1 SUCCESS CRITERIA

In terms of overall building energy intensity improvement, a significant and measurable decrease in EUI (Energy Use Index) in Btu/ft^2 per year would be a minimum of 5% to 10% depending on the energy uses and electrical loads in the building that are not air-conditioning related. Buildings conditioned with unitary equipment typically expend a third to half of their energy use on cooling. The 15% improvement success criteria listed in Table 3.2-1 equates to approximately 5-10% improvement in overall building energy intensity.

3.2 PERFORMANCE OBJECTIVES

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative Performance Objectives			
A. Increase A/C unit energy efficiency	Energy used by A/C unit vs. cooling provided	kW & kWh relative to baseline MBH and Btuh	>15% improvement in energy efficiency relative to baseline
B. Improve facility Indoor Air Quality (IAQ)	Increased time that IAQ meets ASHRAE 62.1 recommendations	CO_2 level and % RH of conditioned space, relative to baseline	>15% increase in fraction of hours IAQ is satisfactory relative to baseline
C. Demonstrate cost effectiveness of new technology	Cost of installed technology relative to energy cost savings	Installed costs, energy cost reduction relative to baseline	BLCC modeling indicates payback perod of <3 years for PAFB and <7 years for MCASB
Qualitative Performance Objectives			
D. Ensure maintainability with existing HVAC staff & resources at demonstration sites	Field assessment of HVAC staff at demonstration sites	Identify critical areas of maintenance & performance, and training needs	Concurrence of HVAC staff supervisors at demonstration sites of maintainability of system & components
E. Evaluate reliability of retrofitted unit relative to expected reliability of base unit	Percentage of time unit performs as designed	Document runtime and downtime for retrofitted unit vs base unit	Retrofitted unit performs as well or better than base unit
F. User satisfaction	Likert-type Scale	Survey data	10% increase in satisfaction over baseline

Table 3.2-1 Performance objectives established for the demonstration.

A. *Increase A/C unit energy efficiency* - Metrics used to measure success are field-measured EER (Energy Efficiency Ratio = Btu/hr cooling / total unit Watts) and IPLV (Integrated Part Load Value – weighted kW/ton) (7) for each demonstration unit, and cooling season electric kWh consumed – both actual and adjusted to TMY2 (Typical Meteorological Year) weather data for adaptation to other climate locations. The expectation for each demonstration unit was for it to exhibit measurable increase in EER and commensurate decrease in energy use for a cooling season. Baseline EER data was collected for the A/C units before modifying them with ClimaStat add-on. At MCASB, the existing Automated Logic monitoring/control system was used to collect data on the demonstration unit, RTU-2 at Building 1283, for more than 2 months of the 2011 cooling season. For the 2012 cooling season, both demonstration units were instrumented fully with new temperature, pressure, humidity, CO2, amps, and power sensors, and baseline operational data was collected for more than 4 months using internet-based Hobolink data logging systems. After both units were modified with the addition of ClimaStat, the same monitoring system was be used to continuously collect data, and additional instrumentation on the modified unit was also collected.

B. *Improve facility Indoor Air Quality (IAQ)* – Unitary A/C systems currently on the market have fixed cooling coil surfaces. When energy efficiency measures are added, such as multiple or multi-stage compressors, or variable fresh airflow and supply air volume, dehumidification capability and fresh air delivery fluctuate. Typically, there is no control function that compensates to meet latent loads during periods of part-load sensible cooling (3, 4). Thus, fresh air quantity is limited to about 20% of the unit airflow, with the remaining 80% being re-circulated air. To address the objective of improved IAQ in the conditioned space, we collected relative humidity (RH) and carbon dioxide (CO_2) data in the zones served by the A/C units prior to retrofitting with ClimaStat to establish a performance baseline. We continued to collect this data after the ClimaStat retrofits, providing a basis for comparison between "before" and "after" retrofit. The measure of success for this objective was an increase in the fraction of hours the RH of the demonstration facility is kept within the desired range, e.g. 50-60% and CO_2 is kept below 1000 ppm. IAQ is characterized via space relative humidity, temperature, and carbon dioxide levels and the fraction of occupied hours which these levels are deemed acceptable. The metric used was the ASHRAE 62.1 IAQ standard and the time that the standard is met in the space conditioned by the demonstration units.

C. *Demonstrate cost effectiveness of new technology* – Using Building Life Cycle Cost (BLCC) software[15] analysis, actual tracked installation materials and labor costs were input versus realized electric savings. The cost effectiveness of a retrofit of ClimaStat to existing equipment, as with the MCASB project, was compared to that of factory-installed ClimaStat option in order to establish a field-retrofit LCC versus a factory-install scenario. During the course of the ClimaStat demonstrations, Advantek engineers utilized local HVAC contractors to service and, if necessary, repair the demonstration units. While not a comprehensive database of expected maintenance costs, data collected was extrapolated over the expected life of the demonstration units and any additional costs that ClimaStat incurs were estimated for the BLCC analysis. Measureable IAQ improvements resulting from introducing

[15] BLCC was developed by NIST and is the standard for Federal Energy Management Program building projects. We will use the most recent version of BLCC for the PC (current version is 5.3.10).

ClimaStat at the buildings were noted and included in the BLCC analysis, if building managers at the demonstration sites could assign a cost savings. At the outset of the demonstration, BLCC-calculated payback periods were considered to be favorable investments if a payback less than 3 years was achieved for new equipment installation at PAFB, and less than 7 years for the field-retrofitted installation at MCASB.

D. _Ensure maintainability of ClimaStat by HVAC staff & resources at demonstration sites_ – Maintainability of a new technology is judged by the staff responsible for keeping the technology in good working order. We worked with DoD service personnel and local contractors at the demonstration sites to install the ClimaStat retrofits and, during the demonstration period, we offered training and guidance on servicing to onsite maintenance staff. ClimaStat uses off-the-shelf components that have the "look and feel" of typical air conditioning and refrigeration technology, so servicing the retrofitted units isn't a significant departure from current staff expertise, maintenance responsibilities, or routine service operations. The measure of success for this objective is the judgment of maintenance supervisors at the demonstration sites that the retrofitted units can be serviced with existing staff, and the absence of a need for critical maintenance interventions. Advantek engineers assigned to the demonstrations provided teaching/training experience in HVAC systems and R&D, and experience with other field-modified A/C units that have been retrofitted with ClimaStat. Advantek engineers local to the two demonstration sites were on call for consultation if questions arise during O&M of ClimaStat units. Demonstration units were fully instrumented for Advantek to monitor real-time operation and conditioned space parameters and quickly identify O&M problems or anomalies. Throughout the demonstrations, we maintained a quick response system with local HVAC staff for dealing with needed maintenance and repair of demonstration units.

E. _Evaluate reliability of ClimaStat-retrofitted unit relative to base unit_ - Reliability of commercial unitary HVAC equipment is a function of initial system design (unit sizing, ductwork, controls, etc.), operating environment, maintenance practices, and user control, as well as manufacturer-determined robustness of technology. To evaluate reliability, we assessed expected reliability of the base demonstration HVAC equipment using operating and maintenance data collected prior to retrofitting with ClimaStat, as well as longer-term maintenance records kept at the demonstration sites. We evaluated a "before retrofit" relative to the "after retrofit" operation of the same or an identical piece of HVAC equipment. After the retrofit, data was collected on the units' operation, as well as interviews from installation staff responsible for operation and maintenance of the demonstration units, and this data was used to compare relative reliability of the base units to the retrofitted units.

F. _User satisfaction_ – Using a Likert-type[16] scale survey instrument with a 5 point response range from "Least satisfied" -1- to "Most satisfied" -5-, occupants at the demonstration sites were surveyed on the performance of the ClimaStat-modified A/C units. The survey was designed to measure satisfaction with the comfort provided by the ClimaStat units and was administered at both sites in February 2013. The survey instrument is included at the end of this report.

[16] A questionnaire on comfort in Likert-type format in which responses are scored along a range.

4 FACILITY / SITE DESCRIPTION

Two demonstration sites were selected based on their representation of relative climatic conditions that would affect operation of commercial unitary air conditioning equipment.

1. Marine Corps Air Station – Beaufort (MCASB), located in Beaufort County, South Carolina, is near the upper edge of the DOE-designated Hot & Humid climate zone.
2. Cape Canaveral Air Force Station (CCAFS), located on Cape Canaveral, Florida, within Patrick Air Force Base, is in the middle of the ASHRAE Hot & Humid climate zone.

These military installations agreed to serve as test beds for direct expansion air conditioning equipment that cools and dehumidifies conditioned spaces in two operational applications: commercial (MCASB) and laboratory (CCAFS). The sites were also selected to demonstrate retrofit of existing equipment using legacy R-22 refrigerant (MCASB), and demonstration of new equipment using R-410a refrigerant (CCAFS). Commitment of the participating installations allowed Advantek engineers to access baseline energy use data; perform adjustments to the baseline equipment; install ClimaStat, and collect performance data on the modified equipment operation.

4.1 FACILITY / SITE SELECTION

4.1.1 MCAS Beaufort Demonstration Site

Marine Corps Air Station Beaufort is a 6900-acre installation located 3 miles north of the city of Beaufort, SC, 70 miles southwest of Charleston, SC and 40 miles northeast of Savannah, GA (Figure 4.1-1). The base hosts operations and support for seven squadrons of Marine F/A-18 Hornets and two Navy F/A-18 squadrons, with 700 Marine and Navy personnel, and 600 civilian

Figure 4.1-1 Location map of MCAS Beaufort Demonstration Site in South Carolina.

personnel supporting the 3,400 personnel of Marine Air Group 31. The base was first commissioned in 1943 and in 2010 was selected for assignment of squadrons of the F-35B, Marine version of the Joint Strike Fighter aircraft, along with a large F-35B training facility. MCASB is representative of a well-established military base that makes significant economic and leadership contributions to the nearby communities. The base is located in a climate zone that calls for significant cooling for 8 months annually, as indicated in Table 4.1-1.

Source : http ://www.degreedays.net/

Month starting	Cooling Degree Days
1/1/2012	47
2/1/2012	68
3/1/2012	213
4/1/2012	274
5/1/2012	464
6/1/2012	506
7/1/2012	716
8/1/2012	609
9/1/2012	508
10/1/2012	280
11/1/2012	48
12/1/2012	54
2012 Total	3787

Table 4.1-1 Cooling Degree Days for MCASB.

Mr. Neil Tisdale, MCASB Utilities Director & Energy Manager, selected Building 1283, the MCASB Base Exchange, as the demonstration site for the ClimaStat demonstration (Figure 4.1-2.) Building 1283 was completed and opened in 2003 and is a large retail facility with gasoline pumps and a convenience mart on one end. The facility is conditioned by 11 unitary rooftop air conditioning/heating units that use standard commercial electric, direct expansion equipment for cooling, and natural gas for heating. The rooftop air conditioners provide some

Figure 4.1-2 Building1283, Base Exchange at MCAS Beaufort.

dehumidification, but the equipment is controlled only by thermostats, with no active humidity control.

All air conditioning equipment at Building 1283 is mounted on the roof, with supply and return air ducts installed through roof penetrations. Electric power and natural gas connections are all made on the roof. MCASB uses a base-wide O&M contractor to perform routine equipment maintenance and inspection. All heating and cooling equipment is monitored and controlled by an Automated Logic Corp. direct digital control (DDC) system, which is maintained by a separate contractor.

4.1.2 Patrick AFB / Cape Canaveral AFS Demonstration Site

Patrick Air Force Base is a 21,500-acre installation located a few miles from Cocoa Beach, FL, about 50 miles east of Orlando, FL (Figure 4.1-3). The host for Patrick AFB since 1991 is the 45th Space Wing (45 SW), which manages all launches of unmanned rockets at Cape Canaveral Air Force Station (CCAFS). The facility is southeast of NASA's Kennedy Space Center. There are more than 35 mission partners and tenants at Patrick / CCAFS, including:

- National Aeronautics and Space Administration (NASA)
- Naval Ordnance Test Unit (NOTU)
- 920th Rescue Wing (920 RQW)
- Defense Equality Opportunity Management Institute (DEOMI)
- Air Force Technical Applications Center (AFTAC)

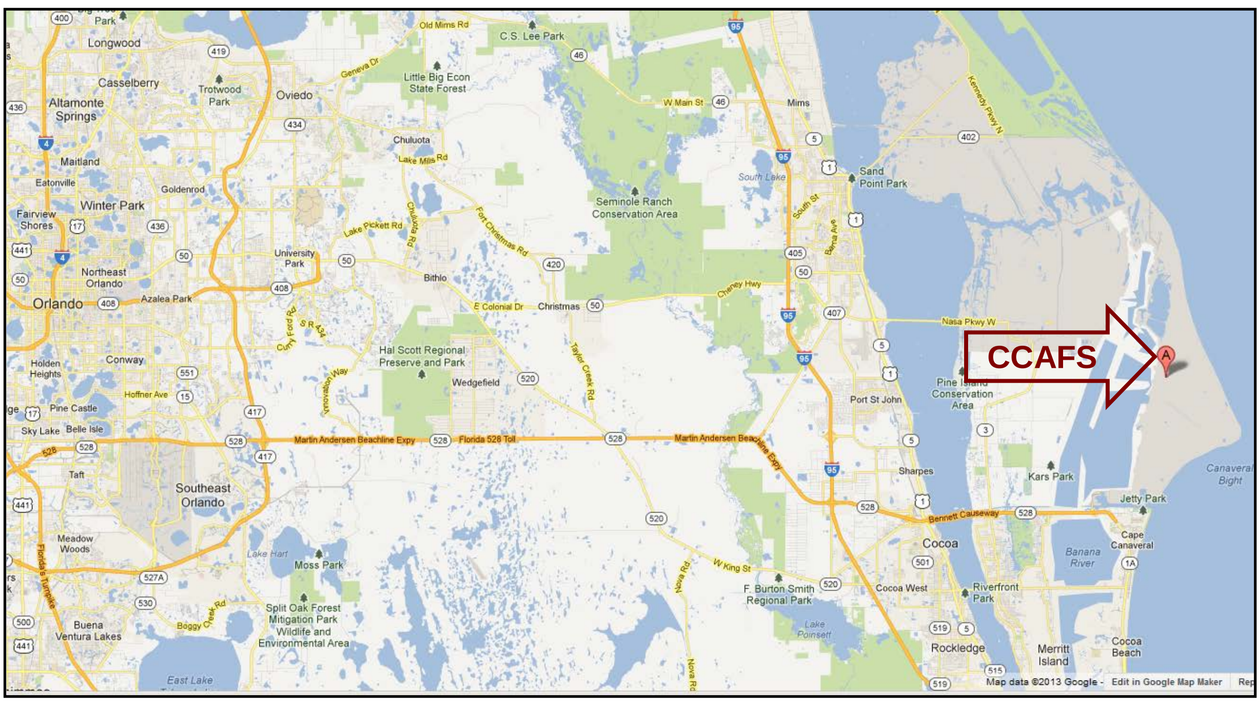

Figure 4.1-3 Location Map Cape Canaveral Air Force Station, east of Orlando, Florida.

Each day, Patrick Air Force Base and Cape Canaveral Air Force Station combine to spend approximately $40,000 on utilities (electricity, gas and water). The 45th Space Wing spent about $30 million on facility energy use last fiscal year.

The Naval Ordnance Test Unit (NOTU) provides technical support for flight test and analysis for ballistic missiles. NOTU is an Echelon III Department of the Navy field command under the cognizance of the Director, Strategic Systems Programs. NOTU operates the Navy Port at Port Canaveral, supporting more than 200 visits a year by submarines and surface ships of the U.S. Atlantic Fleet and foreign navies. There are over 100 NOTU buildings at CCAFS, including missile assembly and checkout facilities, ordnance storage magazines, launch pads, data acquisition and test instrumentation facilities, support shops and offices and the Poseidon and Trident wharves.

The 45th Civil Engineer Squadron (CES) is the largest squadron within the 45th Space Wing, overseeing 14 operating locations with 13,100 personnel -- including three airfields, seven launch complexes, and 1,500 homes. Much like a public works department for a civilian city, the civil engineers assigned to the 45th CES maintain all utilities and facilities at Patrick AFB, Cape Canaveral AFS, Jonathan Dickinson Military Tracking Annex, Malabar Annex, Ramey Solar Observatory, Puerto Rico, Antigua Air Station, West Indies, and Ascension Island. The 45 CES is charged with supporting the Air Force strategic goal of an energy intensity reduction of three percent per year for 10 continuous years.

The ClimaStat demonstration unit is a new unit that replaced a Trane model TCH090 7½ -ton packaged air-conditioning package unit manufactured 5/1999 at NOTU Building 1115, Hangar Y, East side (Figure 4.1-4).

Figure 4.1-4 Hangar Y, NOTU, CCAFS, EDL is at the right (North) side of building.

Mr. Kevin Riley, PE, CEM, AFSPC IOMS Energy Manager, CCAFS and Mr. Chris Cook, 45th Space Wing Resource Efficiency Manager worked with Michael Manning of NOTU facilities

staff to select the Electronics Development Laboratory (EDL), located in Hangar Y at CCAFS as the site for the ClimaStat demonstration. The EDL occupies an area on the north side of Hangar Y, which is conditioned by multiple DX split-systems and ground-mounted package units, all with electric heat and reheat. Hangar Y is about 1000 yards from the Atlantic Ocean and must contend with salty, humid breezes year-round.

Most of the units at the Hangar Y building are from Trane, and while Trane had expressed some interest in participating in the demonstration project, our contact with Carrier Corp. headquarters in Syracuse, NY promptly responded with an offer to provide new equipment at no cost for the site, ostensibly to be a part of the ESTCP demonstration project and to gain a stronger foothold at the base. The 1999 unit identified for replacement with the new unit was selected by CCAFS because it was in poor condition and ready to be replaced, and because the dehumidification needs of the EDL had been particularly challenging (Figure 4.1-5).

Figure 4.1-5 CCAFS unit that was replaced for ClimaStat demonstration.

Staff inside the EDL develop, build and test precision instrumentation, controls, and auxiliary equipment in support of shipboard weapons systems. Each work area in the EDL has a temperature/humidity chart recorder to monitor adherence to the requirement for temperature control at 72F ±1 deg-F and humidity control at 60% ± 5%rh. The charts are certified weekly and archived. The existing Trane unit had 30 kW of electric heat energized for humidity control reheat simultaneously with 7.5 tons (25 kW) of cooling to meet the control conditions, which was very energy intensive.

The ground mount package unit serving the EDL has supply and return ductwork leading into an adjacent mechanical room and from there up and above the ceiling of the EDL where it connects to multiple supply diffusers and return grilles. The existing unit was controlled by a standalone thermostat and an independent humidistat; neither was connected to the building Automated Logic system or the base EMCS.

The location of this environmentally controlled lab on Florida's Atlantic coast represents a significant year-round cooling load. Table 4.1-2 presents the Cooling Degree Data for CCAFS for 2012.

Source: http://www.degreedays.net/

Month starting	Cooling Degree Days
1/1/2012	78
2/1/2012	141
3/1/2012	237
4/1/2012	264
5/1/2012	400
6/1/2012	440
7/1/2012	526
8/1/2012	501
9/1/2012	434
10/1/2012	372
11/1/2012	103
12/1/2012	134
2012 Total	3630

Table 4.1-2 Cooling Degree Days for CCAFS.

4.2 FACILITY/SITE LOCATION AND OPERATIONS

The ClimaStat demonstration site is Building 1283 on MCASB, the Base Exchange facility (Figure 4.2-1), which has 11 unitary air conditioning units located on the roof. Construction on the Building 1283 was completed in 2003, and all the air conditioning units were installed new as part of the construction. The MCASB site was selected to be the retrofit demonstration of ClimaStat technology and would involve selecting air conditioning equipment that had operated for most of its useful life. A typical lifetime assumption for commercial unitary A/C equipment is 15 years.

Working with MCASB Public Works, Advantek engineers identified RTU-2, a 2003 20-ton Trane Voyager unitary A/C unit located on the roof of Building 1283, as the best candidate for the ClimaStat retrofit. Building 1283 is connected to a base-wide direct digital control (DDC) network, which monitors operational conditions continuously, including the status of RTU-2. The building is also connected to an advanced energy metering system, but RTU-2 is not individually metered for electricity usage. MCASB Public Works monitors base energy usage and regularly reports usage relative to an FY 2003 baseline of 94,870 Btu/ft^2, with current usage at 64,020 Btu/ft^2 in November 2012. In 2010, MCASB provided a letter of commitment to participate in a ClimaStat retrofit of RTU-2 on Building 1283, and MCASB managers and O&M contractors contributed significantly during the ESTCP demonstration project duration, March 2011 – January 2013. Advantek engineers were provided access to the demonstration site, RTU-2, and energy use data collected by the MCASB monitoring system.

> Mr. Neil Tisdale, Utilities Director/Energy Manager at MCASB, gave this feedback on the ClimaStat demonstration in January 2013: "The MCCS Maintenance Director is happy with the performance of the unit due to the fact that he has had no complaints. In the maintenance world no complaints is considered a job well done!"

At CCAFS / NOTU, the Electronics Development Laboratory is a challenging and energy-intensive space to air condition, and packaged air conditioners operate in a corrosive environment because of the close proximity to the ocean. The dehumidification requirement for the EDL represents an opportunity for a ClimaStat-equipped air conditioning unit to demonstrate significant energy savings from both reduced cooling requirements and reduced electric reheat requirements.

4.3 FACILITY/SITE CONDITIONS

The MCASB Base Exchange (http://www.mymcx.com/index.cfm/locations/beaufort/) continued normal operation throughout the demonstration project – Monday through Friday: 0600 – 2300, Saturday: 0800 – 2300, and Sunday: 0800 – 2200. Exchange employees were regularly consulted regarding the comfort levels of the space conditioned by RTU-2, and the data acquisition system (DAQ) installed for the demonstration project provided alarms for RTU-2 status, space temperature, and space relative humidity. The demonstration site at MCAS Beaufort is under the management of the Public Works Division, and the retail operations of the Base Exchange are responsive to serving the needs of the 4,200 military and civilian personnel assigned to the base, and their family members. Air conditioning this facility is very similar to the environment of a stand-alone "big box" store, with staff and customers using the space from 15 – 17 hours every day of the week, excepting holidays. The Exchange space is subject to frequent door openings, which provides uncontrolled, but effective, fresh air ventilation. There are also significant heat loads from lighting and vending machines. RTU-2 is controlled by the MCASB DDC system to maintain a temperature setting, but there is no active humidity control of the space. The unit is shut off during hours that the Exchange is closed.

As mentioned previously, the EDL at CCAFS requires active control of both temperature and relative humidity. The hours of operation are Monday thru Friday from 0600 to 1630, closed every other Friday, but the space is maintained at setpoint conditions (72 ± 1ºF, 60 ± 5% RH) 24 hours/day. The system is maintained by the NOTU HVAC Maintenance Shop. EDL employees were regularly consulted regarding temperature and humidity, and the web-based digital controller installed for the demonstration project provided alarms for status, space temperature, and space relative humidity. Throughout the demonstration project the new Carrier unit provided excellent climate control in the EDL while saving energy.

5 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

The ESTCP demonstration is intended to validate that ClimaStat raises the energy efficiency of DX package systems and reduces annual energy consumption and costs; provides a measurable improvement of indoor air quality; operates without adverse maintenance effects; and is cost effective for the military installations hosing the demonstrations. The demonstration units were fully instrumented on both the airflow process and refrigerant cycle. Advantek has considerable experience performing this design, operation, analysis & evaluation, and maintenance work involved in the two demonstrations.

At the time this demonstration was proposed, metrics used to measure success of new air conditioning technology were field-measured EER (Energy Efficiency Ratio = Btu/hr cooling / total unit Watts] and IPLV (Integrated Part Load Value – weighted kW/ton) (5); cooling season electric kWh consumed – both actual and adjusted to TMY2 (Typical Meteorological Year) weather data for adaptation to other climate locations; actual tracked installation materials and labor costs versus realized electric savings; IAQ via space relative humidity, temperature, and carbon dioxide levels and the fraction of occupied hours which these levels are deemed acceptable; and maintenance costs and the number and severity of maintenance interventions, if any. In January 2010, AHRI adopted a new energy performance metric for commercial unitary air conditioning equipment, measured Integrated Energy Efficiency Ratio (IEER) with the same units as EER.[17] The difference between IEER and EER is the ambient temperature of the rating test at full load and part-load operation, along with limits on the supply air temperature and airflow static pressure. EER is rated at 95F outdoor temperature, and IEER is a weighted average of 4 adjusted EERs measured at 95F, 81.5F, 68F, and 65F so that the product rating is a better predictor of actual installed energy use. Further details on the calculation of IEER are discussed in Section 6.0 of this report. Also, rather than adjusting to TMY weather data, it has become more common to calculate the energy use per cooling degree-day (kWh/CDD) for more straightforward adaptation to other climates.

Demonstration comparisons were conducted by way of two methodologies: (1) on same package unit using 'with' versus 'without' and/or (2) 'before' versus 'after' data collection and analysis during one cooling season. Three portable web-based 15-channel data loggers per site were used to collect and store data at 1 minute to 5-minute intervals. During the demonstration period, data verification was performed weekly by plotting the reduced data, allowing the analyst to visually locate significant outlying points that may indicate erroneous data collection or operational problems. The following data was collected via calibrated and verified sensors installed on/in each demonstration system to enable calculation and analysis of accurate performance metrics and the effect of the technology on system operation:

- <u>Dependent system-level variables continuously measured were</u>: System power demand (kW) and energy consumption (kWh); system cooling delivered in terms of both sensible and latent (Btuh); and occupied space air temperature (F), relative humidity (%RH), and

[17] American Heating, Refrigeration, and Air Conditioning Institute (AHRI), ANSI/AHRI Standard 340/360-2007 with Addendum 2, *Performance Rating of Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*, approved by ANSI 10/27/2011.

carbon dioxide level (ppm) differential with respect to ambient carbon dioxide level (6, 7).

- Dependent component-level variables to be continuously measured are: compressor and fan electric (amps), refrigerant pressures and temperatures at the inlet and outlet of the compressor (psig and F); refrigerant flow rate (gpm); coil air face velocity (fpm), inter-component air and refrigerant temperatures (F); and control signals status and voltages (8).

- The independent variable is a binary change of status 'with' versus 'without' the subject technology, ClimaStat. Background independent variables are ambient temperature (F), humidity (%RH), carbon dioxide level (ppm), occupancy status, and time of day / day of week.

Table 5.2-1 on the following page lists the variables measured by data logger channel number.

5.2 BASELINE CHARACTERIZATION

Baseline data was collected before installation of ClimaStat on the demonstration units. For the ClimaStat retrofit of RTU-2 at Building 1283, MCAS Beaufort, Advantek worked with Facilities personnel to tie into the Automated Logic DDC network to collect operational data on RTU-2 beginning in May 2011 through the date that the unit was modified with the addition of ClimaStat, and continued through the demonstration period. Data to be collected from the DDC monitoring system includes:

1. Operational status (on/off) of both unit refrigerant compressors
2. Operational status of circulating air fan
3. Temperature of return air and supply air
4. Thermostat set point
5. Operational status (% open) of outside air damper

Additional data to be collected were electricity used by RTU-2, and relative humidity and CO_2 levels in the conditioned space and outside air at Building 1283.

At NOTU Hangar-Y of CCAFS / PAFB there is an Automated Logic DDC system, however, the EDL is not on the network. So, Advantek utilized the data logger system exclusively for collection of operational data on the demonstration unit beginning January 2012 when the baseline factory package unit was installed through the date that the baseline unit was modified with the ClimaStat add-on, and continued through the demonstration period. Data as listed above in section 5.1 was collected for both the baseline and the demonstration periods.

LOGGER	TYPE/CH	SENSOR	TRANSDUCER	MEASUREMENT	UNITS
LOGGER #1	ANALOG 1	4-20mA	AST	High Pressure 1	PSIG
	ANALOG 2	4-20mA	AST	Low Pressure 1	PSIG
	SMART 1	T		Comprssor Out 1	F
	SMART 2	T		Condenser Out 1	F
	SMART 3	T		LIQHX-OUT-1	F
	SMART 4	T		TXV-OUT-1	F
	SMART 5	T		Evaporator Coil Out 1	F
	SMART 6	T		SUCHX-OUT-1	F
	SMART 7	T		Compressor Out 2	F
	SMART 8	T		Condenser Out 2	F
	SMART 9	T		LIQHX-OUT-2	F
	SMART 10	T		TXV-OUT-2	F
	SMART 11	T		Evaporator Coil Out 2	F
	SMART 12	T		SUCHX-OUT-2	F
	SMART 13	T		Condenser Air Out	F

LOGGER	TYPE/CH	SENSOR	TRANSDUCER	MEASUREMENT	UNITS
LOGGER #2	ANALOG 1	4-20mA	AST	High Pressure 2	PSIG
	ANALOG 2	4-20mA	AST	High Pressure 2	PSIG
	SMART 1	PULSE	FLOW	Liquid Flow 1	GPM
	SMART 2	PULSE	FLOW	Liquid Flow 2	GPM
	SMART 3	T		COIL-TOP-LEFT	F
	SMART 4	T		COIL-TOP-RIGHT	F
	SMART 5	T		COIL-BOT-LEFT	F
	SMART 6	T		COIL-BOT-RIGHT	F
	SMART 7	T		DAMPER-AIR	F
	SMART 8	0-5 Vdc	VFD	VFD-SPEED	HZ
	SMART 9	4-20mA	0-10V	DAMPER-POSITON	%
	SMART 10 SMART 11	T-RH		RA-T/RH	F/%
	SMART 12 SMART 13	T-RH		SA-T/RH	F/%

LOGGER	TYPE/CH	SENSOR	TRANSDUCER	MEASUREMENT	UNITS
LOGGER #3	ANALOG 1	4-20mA	dP in-wc	Coil delta-P	IN-WC
	ANALOG 2	4-20mA	KW	Unit Total Power	KW
	SMART 1	0-5 Vdc	VELOCITY	COIL-TOP-VELOCITY	FPM
	SMART 2	0-5 Vdc	VELOCITY	COIL-BOT-VELOCITY	FPM
	SMART 3	0-5 Vdc	VELOCITY	DAMPER-VELOCITY	FPM
	SMART 4	5-512 mVdc	AMPS	Compressor 1 Amps	AMPS
	SMART 5		AMPS	Compressor 2 Amps	AMPS
	SMART 6	5-512 mVdc	AMPS	Condenser Fan Amps	AMPS
	SMART 7		AMPS	Blower Drive Amps	AMPS
	SMART 8	4-20mA	T-RH-CO2	ROOM-T/RH/CO2	F/%/PPM
	SMART 9	4-20mA			
	SMART 10	4-20mA			
	SMART 11	4-20mA	T-RH-CO2	OA-T/RH/CO2	F/%/PPM
	SMART 12	4-20mA			
	SMART 13	4-20mA			

Table 5.2-1 Listing of data logger sensors and channels for demonstrations.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY COMPONENTS

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5.4 OPERATIONAL TESTING

The reduced and verified data was analyzed to calculate the effect on the performance objective variables; generally energy efficiency, energy consumption, cooling and dehumidification performance and space indoor air quality. Operating data was used to model performance of systems with and without ClimaStat correlated to climatic (outside temperature, relative humidity) and operational variables (setpoint temperature, outside air ventilation, indoor relative humidity and carbon dioxide levels). Modeling was performed using NIST CYCLE_D software and the ORNL Mark 7.04 Heat Pump Model. Details of the data analysis calculation are discussed in Section 6.0 of this report.

Energy consumption was calculated from logged system kW and run time. Sensible cooling performance was calculated using the temperature differential between the system inlet and outlet, and across the cooling coil. Dehumidification performance was calculated via the absolute humidity differential psychrometrically computed using temperature and relative humidity at the system inlet and outlet and across the cooling coils. Total cooling is then the sum of the cooling and dehumidification Btuh, and sensible heat ratio is the sensible cooling divided by the total cooling. These parameters fully characterize system performance and are directly comparable with manufacturer's published data and industry standards.

Total cooling is also calculated from the logged refrigerant pressure differential between compressor inlet and outlet, along with the temperatures at the same locations, and the refrigerant mass flow rate computed from the refrigerant volume flow rate and density using specialized software. Together with the system kW, the energy efficiency ratio is calculated as the total cooling Btuh divided by the system kW. These results were statistically correlated with ambient air conditions to determine the effect of the operating environment on performance; for example, EER versus ambient temperature is useful for predicting energy usage at other locations. Other useful statistics calculated are average, maximum and minimum values, the standard deviation, and the percentile.

Space indoor air quality was evaluated by counting the number of data sample intervals during which the indoor space temperature, humidity, and carbon dioxide level were within the comfort parameters defined by ASHRAE Standard 62, 1-2010 *aka* "The IAQ Standard" and Standard 55 aka "The Comfort Standard." Typically, this means temperature between 72°F and 77°F, humidity between 50% and 60%$_{rh}$, and carbon dioxide level less than 700 ppm above outdoor ambient level. The number of sample intervals multiplied by the interval length, divided by the total elapsed data collection period yields the fraction of time IAQ is deemed satisfactory by 80% of a statistical group of occupants. These parameters were compared 'with' versus 'without' ClimaStat.

Final analysis focused on determination and prediction of improvement in energy efficiency relative to cost of installation using a life cycle cost assessment, with success defined by a simple payback period of less than 10 years, and a net present value greater than the incremental cost, and/or criteria determined by the ESTCP program, and by realized improvements in indoor air quality.

5.5 SAMPLING PROTOCOL

The sensor points listed in Table 5.2-1 above were sampled at 30 second intervals by the data logging system, and the average of every 10 samples were recorded every 5 minutes in a comma delimited text file. The recording rate could be temporarily be increased to 1 minute (2 samples) when more detail is required, and reduced to 15 minutes (30 samples) for long term trends. There were a total of 45 sensor channels at each site. Data was available in near-real-time (within 1 hour) to all project personnel by secure web via any standard web browser at tinyurl.com/ccafs-carrier and tinyurl.com/mcas-traane. CSV files containing all data were downloaded at 10 to 14 day intervals into Excel files for further analysis.

Demonstration comparisons were conducted by way of two methodologies: on same package unit using ‘with’ versus ‘without’ and/or ‘before’ versus ‘after’ data collection and analysis over one cooling season. Data verification was performed weekly by plotting the reduced data, allowing the analyst to visually locate significant outlying points that may indicate erroneous data collection or operational problems. The following data was collected via calibrated and verified sensors installed on/in the system to enable calculation and analysis of accurate performance metrics and the effect of the technology on system operation:

- Dependent system-level variables continuously measured are system power demand (kW) and energy consumption (kWh); system cooling delivered in terms of both sensible and latent (Btuh); and occupied space air temperature (F), relative humidity (%RH), and carbon dioxide level (ppm) differential with respect to ambient carbon dioxide level (6, 7).

- User satisfaction survey questions were adopted from the survey instrument used by ASHRAE in evaluation new technology demonstrations: The Occupant Indoor Environmental Quality (IEQ) Survey™ from the Center for the Built Environment at Lawrence Berkeley – http://www.cbe.berkeley.edu/research/survey.htm. Questions applicable to this project are:

  1. How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)? [note: calibration question]
  2. How satisfied are you with the temperature in your workspace?
  3. Overall, does your thermal comfort in your workspace enhance or interfere with your ability to get your job done?
  4. How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?
  5. Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?
  6. How satisfied are you with general maintenance of the building?
  7. Does the cleanliness and maintenance of this building enhance or interfere with your ability to get your job done?
  8. Considering energy use, how efficiently is this building performing in your opinion?

Dependent component-level variables to be continuously measured are: compressor and fan electric (amps), refrigerant pressures and temperatures at the inlet and outlet of the

compressor (psig and F); refrigerant flow rate (gpm); coil air face velocity (fpm), inter-component air and refrigerant temperatures (F); and control signals status and voltages (8). The independent variable is a binary change of status 'with' versus 'without' the subject technology, ClimaStat. Background independent variables are ambient temperature (F), humidity (%RH), carbon dioxide level (ppm), occupancy status, and time of day / day of week.

5.6 EQUIPMENT CALIBRATION AND DATA QUALITY ISSUES

5.6.1 Calibration of Equipment

The data loggers including all sensors underwent a bench top setup and 2-points per sensor calibration verification within 10-days before being transported to each demonstration site. Any sensors not within the sensor manufacturer's calibration tolerances were immediately returned to the manufacturer for calibration or replacement. Refrigerant temperature sensors were placed together in an ice bath while output was logged at 5-minute intervals for 10-hours as the ice bath warmed to room temperature and then to 120F., calibration tolerance was ±0.36 degrees-F. Pressure sensors were connected to a container of refrigerant (R-22 or R-410 depending on the sensor) and the saturation pressure of the refrigerant was calculated using Dupont property correlations at a range of pressures, calibration tolerance was 1% of full scale (either 500, 250, or 200 psig depending on the sensor). Flow sensors were bench verified using a known volume flow of water per unit time. Amp, CO_2, humidity, and kW sensors were bench tested in a similar manner against a known quantity.

Once sensors were installed, periodic in situ calibration checks were performed when the package unit had been off long enough for system temperatures and pressures to stabilize and it could be assumed that all temperature and pressure data should be equal. Amp and kW sensors were periodically checked in situ with high quality, recently calibrated portable meters. Flow sensors were field calibrated against a high quality ±1% portable ultrasonic flow meter.

5.6.2 Quality Assurance Sampling

Upon installation at the demonstration sites, a quality assurance sampling protocol was performed for verification of data logger / sensor accuracy. By operating the RTU with compressors *off* for about 90 minutes, all temperatures, pressures, voltages and RHs were allowed to stabilize at an expected common value, which was also verified with calibrated hand-held portable instruments. Air velocity, unit power kW and component electric Amperage were also checked against high-accuracy hand-held portable instruments. A record of logged versus calibration values was maintained starting with this initial sampling. At bi-weekly intervals, compressor *off* periods in the data sets was ear-marked for on-going quality assurance sampling. Any data accuracy discrepancies were checked onsite with hand-held instrumentation, and any suspect sensor(s) was re-calibrated or replaced.

6 PERFORMANCE ASSESSMENT

6.1 INCREASE OF AIR-CONDITIONING EFFICIENCY

6.1.1 Theoretical Modeling

Analysis of an R-410a Copeland Scroll compressor using NIST CYCLE_D software at 115 F (46.1 C) condensing temperature and 45 F (7.2 C) evaporating temperature yields the following results; p-h state diagrams are shown in Figure 6.1-1 (standard cycle, left; ClimaStat cycle, right). NIST CYCLE_D was used to isolate the effect of thermodynamic refrigeration cycle variations used in ClimaStat, thus the calculated improvement in efficiency via CYCLE_D is exclusive of gains from the increase in heat transfer effectiveness and any changes in unit operation such as controls and fan motors. The standard cycle COP is 3.41 / EER 11.6. The ClimaStat cycle COP of 3.74 / EER 12.8 shows an improvement of 9.6% assuming no liquid and zero superheat at the evaporator exit. COP is improved further by allowing liquid at the evaporator exit; however, the software does not yet have that capability.

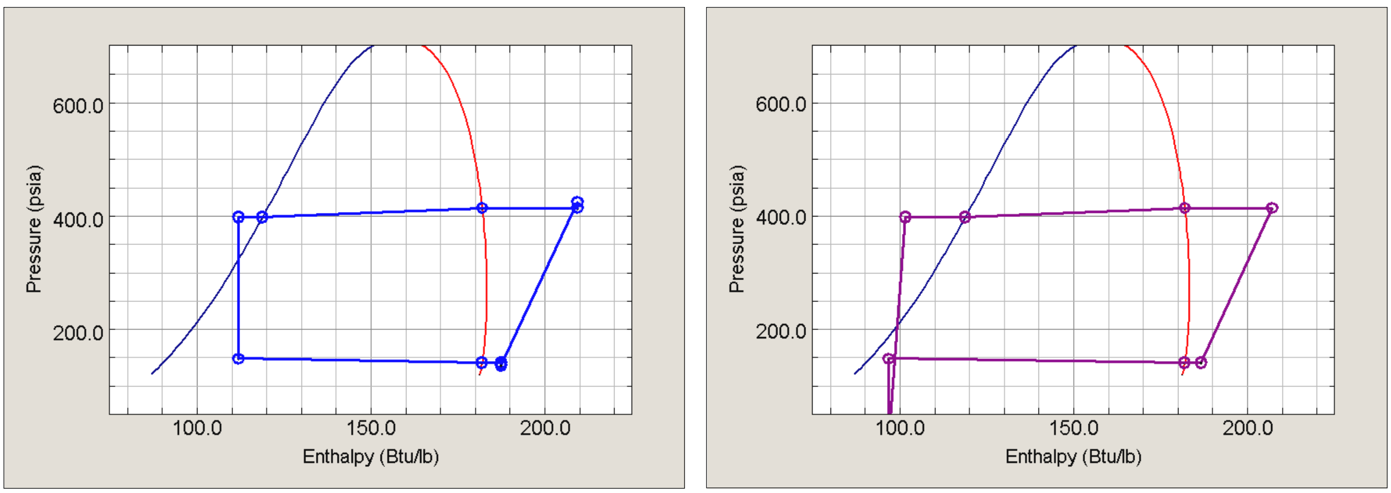

Figure 6.1-1 P-h Diagrams for Standard Cycle (left) and ClimaStat cycle (right) from NIST CYCLE_D.

Modeling of two commercial package units using the DOE/ORNL Heat Pump Design Model Mark 7.04a provided useful results. This DOE/ORNL-developed software is a rigorous and highly detailed research tool for use in the steady-state design analysis of unitary equipment.[18] It is based on state of the art air-side and refrigerant-side heat transfer and pressure drop correlations, and AHRI compressor maps that have been verified through ASHRAE 1173-TRP. The software was used to model four operating conditions for two types of equipment, each both in standard factory configuration and with ClimaStat component variants applied. This modeling takes into account all of the effects of thermodynamic refrigeration cycle variations, thus the calculated improvement in efficiency includes secondary offsets as well as gains from the increase in heat transfer effectiveness and equipment modifications including damper bypass airflow and fan motor speed.

[18] Rice, Keith, Zhiming Gao, and Bill Jackson. Development of DOE/ORNL Heat Pump Design Model Mark 7 Version, Oak Ridge National Lab, February 2006

The four operating conditions satisfy the full load and part-load IEER rating criteria set forth in ANSI/AHRI Standard 340/360-2007, and the IEER of each unit configuration was calculated accordingly. Equipment types that were modeled are an R-410a dual-circuit 8½-ton (29.8 kW) 13.2 IEER TXV-equipped package unit (the demonstration unit at CCAFS), and an R-22 dual-circuit 20-ton (70.1 kW) 11.2 IPLV orifice-equipped rooftop unit (the demonstration unit at MCASB). Figure 6.1-2 shows model output for the R-410a standard factory configuration, the diagram shows detailed refrigerant statepoint and performance information that was used to optimize the application.

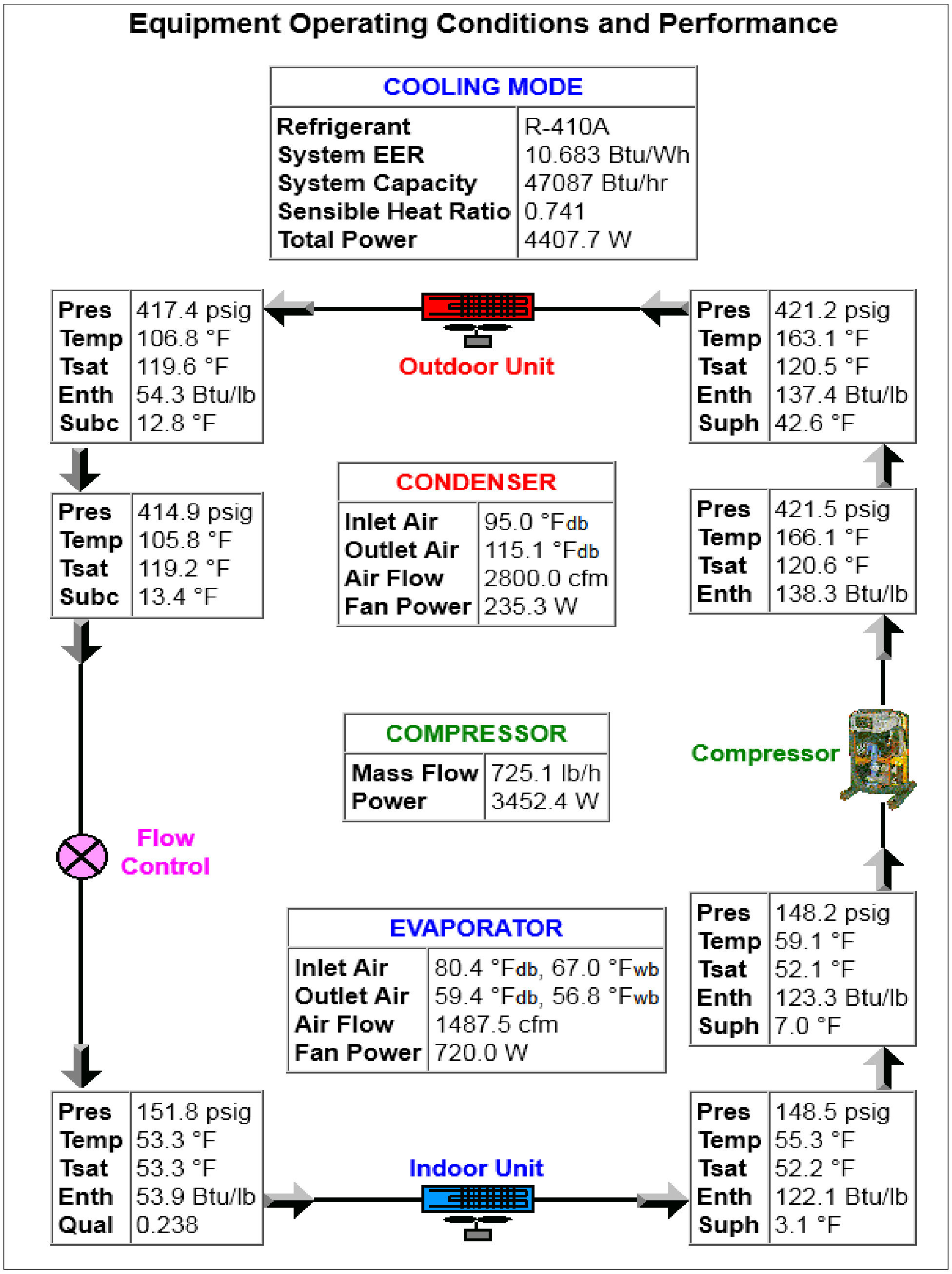

Figure 6.1-2 System operating conditions and performance from ORNL Mark 7.

Results show an IEER increase of 19.7% for the modified R-22 unit and 27.1% for the modified R-410a unit, relative to the standard factory rated configuration for these units. Figure 6.1-3 compares the performance results given by the modeling for the R-410a unit (indicated in the table as model-C) and the R-22 unit (model-T). Results indicate that refrigerant 410a better responds to the effect of the liquid-suction heat exchange due to its higher $c_p \Delta T/h_{fg}$ characteristics at the variant operating points. The cycle variation combined with a change of coil circuiting from face-split to interlaced in model-C impacts part-load dehumidification capacity along with contributing to the greater cooling capacity and IEER increase than obtained with the model-T.

	Model-C		Model-T	
Unit Configuration	**Standard**	**Variant**	**Standard**	**Variant**
Refrigerant	R-410a		R-22	
Nominal Tons	8.5		20	
Expansion Type	TXV		Orifice	TXV
Evaporator Coil	4 row/15 fpi	5 row/14 fpi	4 row/15 fpi	4 row/16 fpi
Circuiting	Face split	Interlaced	Interlaced	Interlaced
Evaporator Face Area sqft	11.1	8.6	26.0	20.3
Face Velocity FPM	268	372	283	305
Modeling Results				
Cooling Capacity Btuh	**96,998**	**119,705**	**249,880**	**256,225**
kW @ 95F ambient	8.05	8.40	23.7	23.0
SHR @ 81.5F ambient	0.72	0.65	0.72	0.64
Supply airflow CFM	2975	3200	7350	6200
Supply Air F	57.0	56.1	57.3	54.2
Duct Static in-wc	0.40	0.30	0.40	
EER @ 95F ambient	12.2	14.2	10.6	11.1
IEER	**13.5**	**17.1**	**11.2**	**13.5**
Percent Increase IEER	27.1%		19.7%	

Figure 6.1-3 Summary of DOE/ORNL Mark 7 modeling comparison.

6.1.2 Demonstration Results

Performance Objective	Success Criteria	PERFORMANCE ASSESSMENT
Quantitative Performance Assessment		
A. Increase A/C unit energy efficiency	>15% improvement in energy efficiency relative to baseline	MCASB: 29.2% increase in unit energy efficiency and 26.1% decrease in annual energy usage. CCAFS: 17.4% increase in unit energy efficiency, together with 33.4% increase in dehumidification capacity; 24.3% decrease in annual energy usage.
B. Improve facility Indoor Air Quality (IAQ)	>15% increase in fraction of hours IAQ is satisfactory relative to baseline	No statistically significant improvement or degradation of IAQ was measured. Baseline IAQ was excellent and entirely satisfactory, thus little potential for improvement was realized.
C. Demonstrate cost effectiveness of new technology	BLCC modeling indicates payback period of <3 years for CCAFS and <7 years for MCASB	2.6 year payback period for new equipment implementation at CCAFS. 4.0 year payback period for the field retrofit of an existing unit at MCASB.
Qualitative Performance Assessment		
D. Ensure maintainability of ClimaStat with existing HVAC staff & resources at demonstration sites	Concurrence of HVAC staff supervisors at demonstration sites of maintainability of system & components	Facilities maintenance supervisor at CCAFS points out just 1 minor maintenance issue related to harmonics from the VFD, which we solved by installation of an electronic filter. Public Works supervisor at MCASB says, "The MCCS Maintenance Director is happy with the performance of the unit due to the fact that he has had no complaints. In the maintenance world no complaints is considered a job well done!"
E. Evaluate reliability of retrofitted unit relative to expected reliability of base unit	Retrofitted unit performs as well or better than base unit	No significant downtime on either unit after 8 months of ClimaStat operation, other than a fuse and a failed fan relay which are normal maintenance items unrelated to ClimaStat. Units are performing better than base unit.
F. User satisfaction	10% increase in satisfaction over baseline	No significant change in satisfaction with workplace comfort. Responses among occupants varied widely, indicating comfort related to other factors.

Table 6.1-1 Objectives and success criteria assessment of demonstrations.

Four operating conditions satisfy the full load and part-load IEER rating criteria set forth in ANSI/AHRI Standard 340/360-2007 and the IEER of each unit configuration was calculated accordingly. To obtain performance at the specified A, B, C, and D rating conditions of 95F, 81.5F, 68F, and 65F ambient and 80/67F db/wb entering air, linear interpolation between data points was used as indicated acceptable by section 6.2.2 of the Standard: "EER is determined by plotting the tested EER vs. the percent load and using straight line segments to connect the actual performance points. Linear interpolation is used to determine the EER at 75%, 50% and 25% net capacity." The IEER was then calculated according to section 6.2.2 of Standard 340/360 using the formula,

$$\mathbf{IEER = (0.020 \cdot A) + (0.617 \cdot B) + (0.238 \cdot C) + (0.125 \cdot D)}$$

where A, B, C, and D are the calculated interpolated EER at each of the rating points.

Data collected at 1-minute sampling rate was analyzed to evaluate the performance of each component of the package units, as well as total system performance, in various operating modes and conditions. Overall comparative results are summarized in Figure 6.1-4. Data sets for the standard unit span from January thru August, and for the modified units from August thru December 2012. Unit GPS coordinates are given in the table for access to aerial views of the unit locations using resources such as Google Maps. The investigators found a significant increase in the EER, IEER and humidity control performance of both units along with decreased energy consumption, while maintaining the already excellent comfort and ventilation levels. Overall, the measured IEER increase of the retrofitted, 8-year old Trane unit at MCASB was 19.4% compared with the catalog-rated IEER, increasing from 11.2 to 13.4. At CCAFS, the overall measured increase in IEER was less dramatic, increasing 11.2%, from 13.2 to 14.7.

The investigators believe the smaller improvement in IEER at CCAFS as compared with MCASB is due to the frequent compressor cycling and nearly constant need for dehumidification, which reduced baseline IEER 5.3% below the catalog rating of the unit at CCAFS even though it was a new unit. However, dehumidification reheat energy use – not accounted for by the IEER or shown in Figure 6.1-4 – was reduced by an order of magnitude as discussed below.

Unit configuration differences between the two demonstration sites and between the baseline and ClimaStat units are also highlighted in Figure 6.1-4. Perhaps the most significant difference is low ODP refrigerant R-410a (Carrier Puron®) is used at CCAFS, while the older Trane unit uses legacy R-22 that is more typical of the large base of existing installed equipment. Cooling coil face area was reduced by 20% in both units, which was partially compensated for by an additional coil row in the Carrier unit (from 4 rows to 5 rows), higher fin density in the Trane unit (from 15 fins per inch to 16 fins per inch), and higher face velocity as called for by the ClimaStat controls. The investigators believe another site-specific factor limiting the measured IEER improvement at CCAFS is circuiting of the factory Carrier coil: the face-split coil is preferable for high humidity applications to the ClimaStat interlaced coil. The factory expansion device in the Trane unit is a set of short-orifices, which were replaced by a TXV (thermostatic expansion valve); replacement of orifice sets with a TXV typically gives a 2~5% improvement in IEER in any unit.

The instrument laboratory served by the Florida unit requires precise temperature and humidity control within ±1 deg-F and ±5%rh at setpoints of 72F (22.2 C) and 60%rh, and has a large influx of fresh, humid sea coast air. To satisfy setpoints under these extreme conditions, both the new standard unit (9 kW) and the existing unit it replaced (28 kW) required prodigious use of electric reheat. The ClimasStat-modified unit (4 kW) did not require nearly as much reheat energy as the standard unit did: controls called for reheat only 0.5% of the run hours, which accounted for 1.3% of the system energy use, while staying within range of setpoint at least 80% of the total hours, including unoccupied and downtime hours. In addition to these reheat savings, the modified unit efficiency was 11.2% improved over the standard unit from IEER 13.2 to IEER 14.7 with the unit in maximum dehumidification mode almost continuously. Note that in general, controlled dehumidification tends to decrease the efficiency of DX package units.

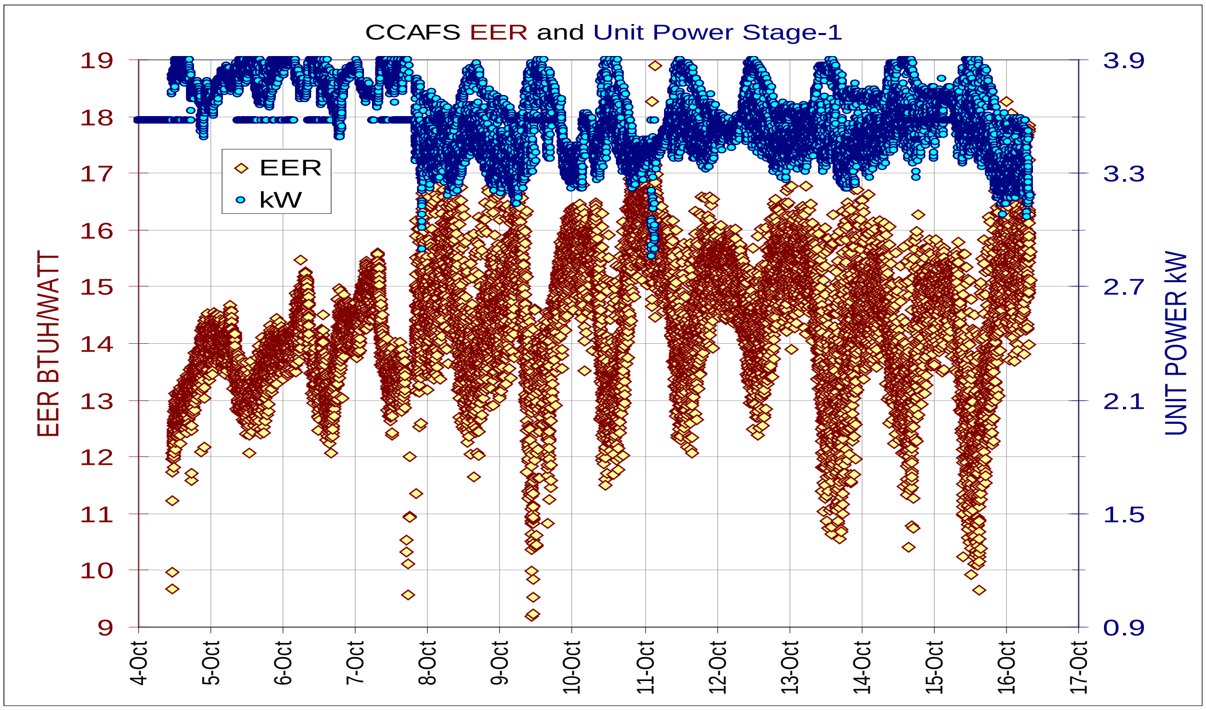

Figure 6.1-4 Plot showing measured EER and total unit power Stage-1.

Measured EER and total unit kW for a two week period in early October are plotted in Figure 6.1-4. The values cycle daily with the rise and fall of the outdoor ambient temperature – warmer temperatures tend to raise the compressor lift, thereby increasing unit kW power demand. The kW peaks correspond to the EER valleys as expected, and the stray high and low points are compressor start and stop transients, which were within 3.48 standard deviations and thus are included in the EER calculation.

An important condition to be noted together with the CCAFS data is the frequent compressor cycling, which is well known to reduce energy efficiency. The tight temperature limits of the lab space at CCAFS required a 1 degree-F deadband to be set on the controller, with no limit on the number of compressor cycles per hour. This is in contrast to a more typical application, such as the Exchange at MCASB, which allows 2-degree swings in space temperature above and below the setpoint and a 10 cycle limit. Compressors in the Trane unit at MCASB had a cycle

period of 20 minutes up to hours, compared with just a few minutes for the compressors in the Carrier unit at CCAFS. These observations together with the ORNL Mark 7 modeling predictions lead the investigators to believe cycling significantly limited the measured energy efficiency improvement at CCAFS.

The Base Exchange retail store served by the MCASB unit required a bit less dehumidification than was being provided by the baseline unit to limit humidity to 60%rh, and reheat controls were not provided nor were they needed. The modified unit efficiency was 19.4% improved over the standard unit factory rating from IEER 11.2 to IEER 13.4 with the unit varying its dehumidification capacity to match the space load. EER @95F increased by 10.4% from the standard unit's 10.6 to the modified unit at 11.7. This improvement is in addition to the increase in IEER from 7.8 to 9.5 from repairs and cleaning of the unit as it was found at project kick-off. The bypass damper modulated as expected according to programming of the base EMCS in response to the deviation of space relative humidity from setpoint.

6.2 DEMONSTRATION DATA ANALYSIS

6.2.1 Analysis Procedure and Findings

Comparative data sets for "with" versus "without" analysis were identified according to weather conditions for 7 to 12 day periods that would include one weekend. Periods where the average, mean and median ambient temperature, relative humidity and dew point were comparable, along with approximately equivalent cooling degree-days were sought.

Raw data sets for the subject periods were downloaded from the data loggers and input to a filtering process to capture periods when the equipment was powered and either one or two compressors were energized. The data was further filtered to remove the peak transient conditions that occur in the first minute or two after a compressor starts, by application of Chauvenet's criterion[19]. Accordingly, the mean and the standard deviation of compressor amps, discharge pressure, and suction pressure were calculated and values greater than 3.48 standard deviations above and 3.48 standard deviations below the mean were culled from the data set. The data that remains is consistent with the steady state operating conditions needed to calculate IEER.

Each data set was then separated into three distinct subsets for all further analysis: (a) data from refrigerant circuit #1 where one compressor only was energized – the Stage-I compressor, (b) data from refrigerant circuit #1 where both compressors were energized and (c) data from refrigerant circuit #2 where both compressors were energized – Stage-II. The analysis then proceeds from one system component to the next in this order, as end values from the calculations of a predecessor component are prerequisite to calculations of the next component: compressor, condenser coil, liquid-suction heat exchanger (not in baseline), evaporator coil, and bypass damper (not in baseline).

[19] In statistical theory, Chauvenet's criterion (William Chauvenet) is a means of assessing whether one piece of experimental data — an outlier — from a set of observations, is likely to be spurious.

The compressor lift ratio, discharge and suction saturation pressures, temperatures, and refrigerant superheat degrees were calculated for each data point, separately for each of the three data subsets of each data set. The refrigerant mass flow rates through the compressors are calculated using published refrigerant R-410a mass flow rate correlations for Copeland Model ZP42K5E-TF5 compressor for the Carrier unit at CCAFS, and model ZRT122K3-TF5 for the Trane unit at MCASB, which were calibrated for a range of suction and discharge superheat values measured in situ against the liquid flow sensors installed in each unit and a portable ultrasonic flow meter. Typical refrigerant mass flow rate data is shown in Figure 6.2-1 along with compressor discharge and suction pressures of circuit-1 of the Carrier baseline unit at CCAFS from June 2 through June 16, 2012. Compressor specific amps were calculated as refrigerant mass flow in lbs per hour per amp, which was used to screen for operating issues such as a failed condenser fan motor or low refrigerant charge.

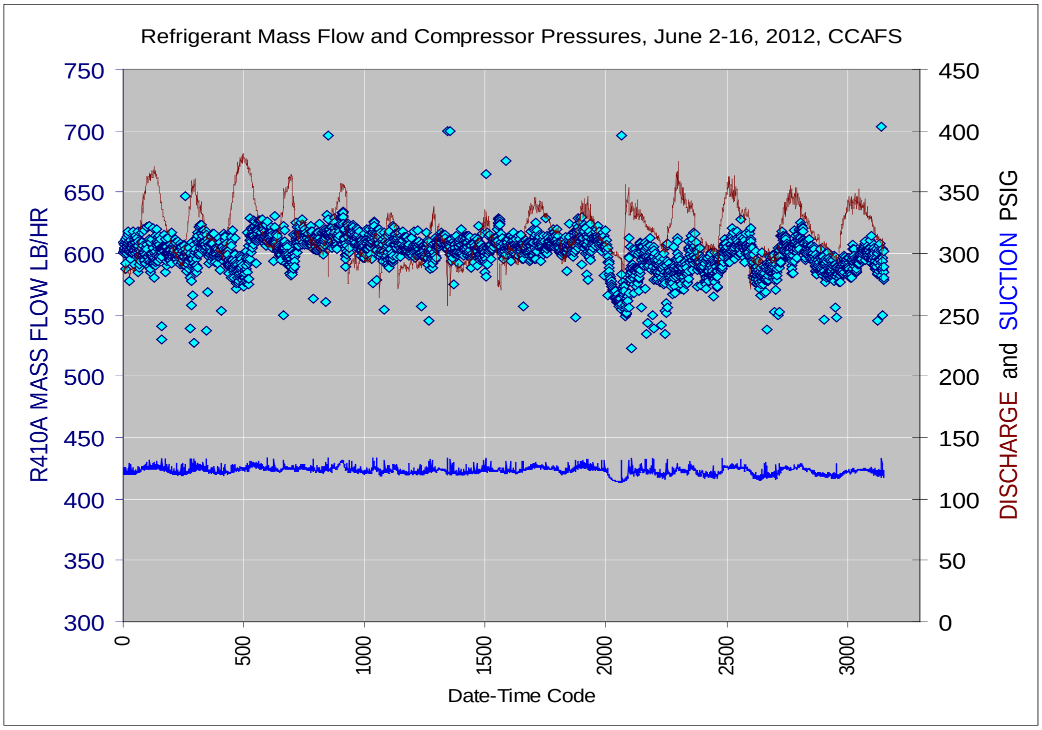

Figure 6.2-1 Time series of refrigerant flow and discharge & suction pressures.

The condenser coil calculations are prerequisite to calculation of the refrigerant cycle COP, condenser heat exchange effectiveness and ambient temperature approach. Having the compressor refrigerant mass flow rates, and the entering and leaving enthalpies of the condenser coil from the above liquid-suction heat exchanger analysis, condenser coil heat transfer is then simply the enthalpy difference in units of Btu per lb multiplied by the mass flow rate in units of lb per hour to give Btu per hour (Btuh), shown in Figure 6.2-2 as Tons. Figure 6.2-2 shows refrigerant sub-cooling degrees-F exiting the condenser and heat transfer Tons in circuit-2, Stage II of the Trane baseline unit at MCASB from July 25 thru August 5, 2012. The cycle COP is calculated as the evaporator heat transfer or cooling effect, divided by the work input, which is the difference between the condenser and evaporator heat flows.

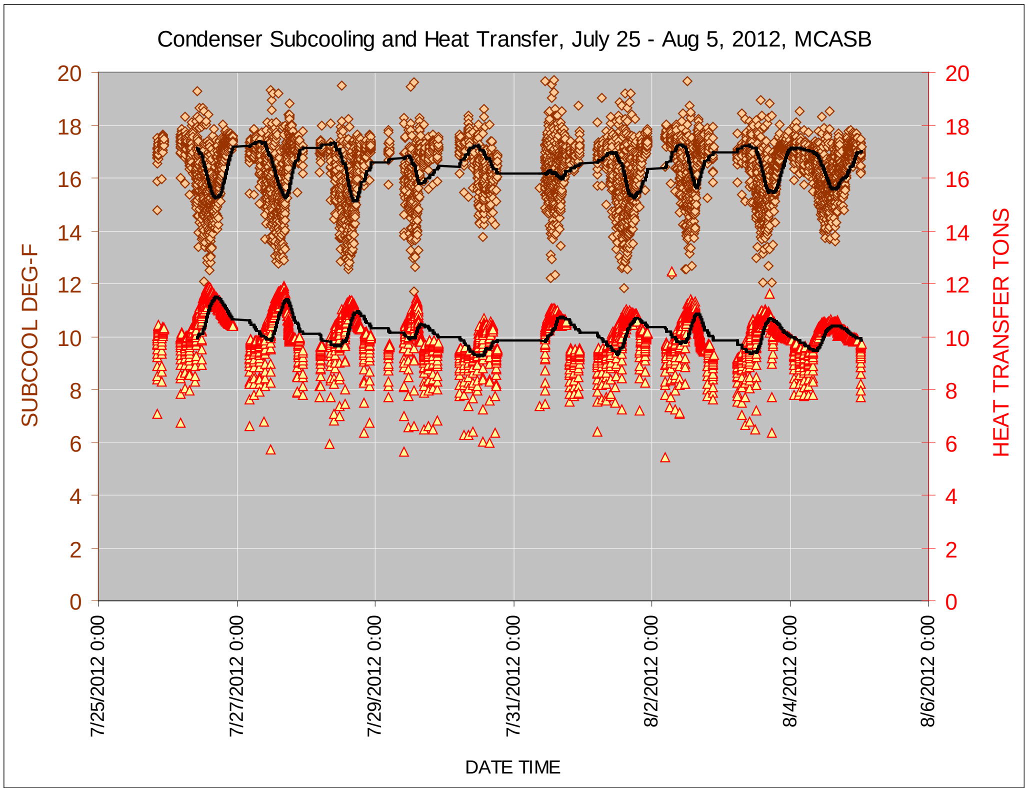

Figure 6.2-2 Refrigerant sub-cooling and heat transfer of baseline unit at MCASB.

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The evaporator calculations are critical to determining the cooling capacity of the unit. Having the compressor refrigerant mass flow rates, and the entering and leaving enthalpies of the evaporator coil from the above liquid-suction heat exchanger analysis, evaporator coil heat transfer is then simply the enthalpy difference in units of Btu per lb multiplied by the mass flow rate in units of lb per hour to give Btu per hour (Btuh). Data for evaporator heat transfer Tons is plotted in Figure 6.2-4, along with the refrigerant temperature exiting the TXV / entering the coil. Figure 6.2-4 is a time series of refrigerant temperature exiting the thermostatic expansion valve and evaporator heat transfer Tons in circuit-1 of the Carrier baseline unit at CCAFS from June 2 thru 16, 2012. The airside evaporator conditions across the evaporator coil are used to calculate sensible-to-total and latent-to-total heat transfer ratios, volume airflow rate, and airside heat transfer coefficient.

EER can then be calculated as the total cooling rate in units of Btuh divided by the electric power demand in units of Watts; this yields a minute-by-minute efficiency value that represents the instantaneous EER at the particular conditions of that data point. To support calculation of the IEER value at ANSI/AHRI Standard 340/360-2007 80F/67wb evaporator air entering conditions and the various ambient temperatures required, evaporator heat transfer is adjusted to 80F/67wb using correlations of published performance data for the Carrier (CCAFS) and Trane (MCASB) models installed at the demonstration sites. Then, compressor power demand and total cooling capacity adjustments are correlated for each data set by linear regression analysis of cooling capacity and power demand versus ambient temperature.

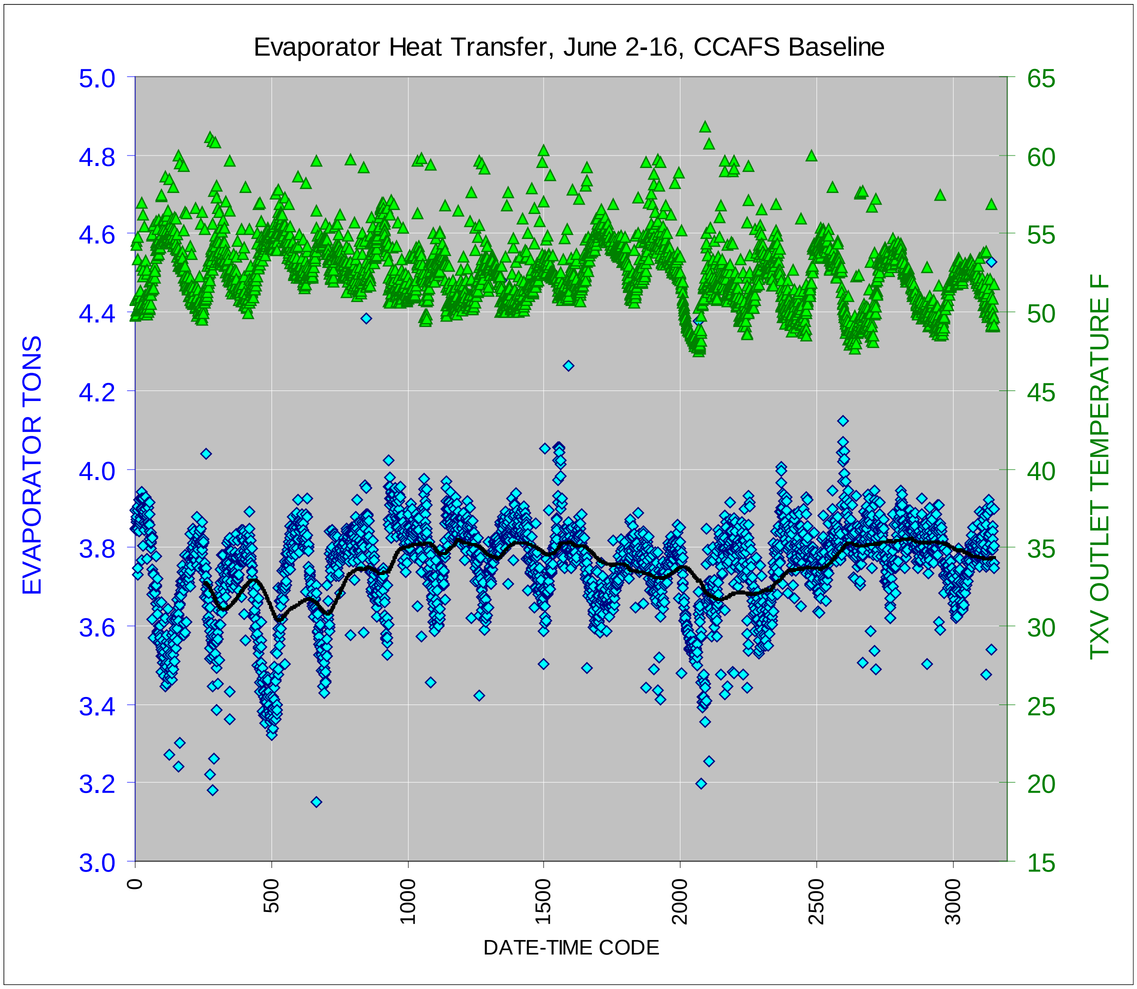


Figure 6.2-3 Refrigerant temperature exiting theTXV and evaporator heat transfer.

6.2.2 Accuracy of Calculations

A propagation of error analysis was performed using a sensitivity analysis technique, to quantify how the uncertainty in the output of the IEER calculation can be apportioned to uncertainty in the temperature, humidity, pressure, flow, and power inputs. Sensitivity analysis was performed by running the calculation a number of times, and incrementing one input variable at a time, known as an OAT sampling-based approach[20]. This assumes independence between inputs, which is a reasonable assumption here. There is no connection between temperature, pressure, flow, and power inputs; there is, however, a minimal degree of dependence between relative humidity and temperature inputs, though both signals come from a single combination temperature and humidity sensor.

The uncertainty in each of the input variables was obtained from manufacturer's specifications,

[20] J.C. Helton, J.D. Johnson, C.J. Salaberry, and C.B. Storlie, 2006, Survey of sampling based methods for uncertainty and sensitivity analysis. Reliability Engineering and System Safety, 91:1175–1209.

after sensor outputs were bench verified against a calibration standard, and against the other sensors of the same type, to be within the manufacturer's stated tolerances. Out of tolerance sensors were replaced, or compensated for in output scaling factors if the calibration offset was minimal. The uncertainty of each of the inputs and the resulting uncertainty in the IEER output are listed in Figure 6.2-5, which shows calculated IEER values from measured data have an accuracy of about ±4.7% or ±0.64 Btuh/Watt. From this analysis it was concluded that the results of the analysis are accurate to within ±4.7% and the IEER values have an uncertainty of 0.64 Btuh/Watt (two significant figures).

Sensitivity - Uncertainty Analysis

Variable	accuracy	IEER	delta	%-delta
Base	±	13.447		
Temperature [F]	0.36	13.364	-0.0832	-0.62%
Humidity [%rh]	2.5%	13.264	-0.1831	-1.36%
Pressure [psig]	3.75	13.926	0.4788	3.56%
Flow [lbm/hr]	2.5%	13.754	0.3076	2.29%
Power [kW]	1.5%	13.249	-0.1976	-1.47%
RMS Error of IEER	0.64		0.6351	4.72%

Figure 6.2-4 Results of sensitivity error analysis.

The IEER uncertainty values of ±4.7% and 0.64 Btuh/Watt are significant relative to the 15% IEER improvement being sought, which is an delta of 1.7 Btuh/Watt for the Trane unit at MCASB and 2.0 Btuh/Watt for the Carrier unit at CCAFS. However, because all calculations are performed using data from the same sensors installed in the same positions, and the same equations, formulae calibrations and/or correlations were used in the analysis and comparison of the data, the same uncertainty in the baseline IEER equally applies to the ClimaStat IEER in the same direction (high or low). Thus, the calculated IEER values are directly comparable to each other with better certainty than comparisons with values obtained from other sources, such as factory ratings.

6.3 RESULTS OF PERFORMANCE COMPARISONS

The improvement in energy efficiency attributable to the ClimaStat technology was assessed by comparing the measured IEER (Integrated Energy Efficiency Rating) and EER (Energy Efficiency Ratio) of the ClimaStat units against both (a) the manufacturer's product data, and (b) the measured baseline performance of the same unit prior to adding ClimaStat. In Figure 6.3-1 the baseline factory unit is labeled "Standard" and the ClimaStat unit is labeled "Modified."

The results show the measured IEER of the ClimaStat unit is 7.3% higher than the factory rating of the Carrier unit at CCAFS, and 19.4% higher than the factory rating of the Trane unit at MCASB. It is important to note that "Standard" factory product ratings represent *ideal conditions in a testing laboratory* designed to maximize performance, while the "Modified" ClimaStat measurements are field data under actual and sometimes severe operating conditions.

FIELD TEST RESULTS	Florida site		South Carolina site	
Location	Cape Canvaeral AFS		Marine Corps AS	
Unit GPS Coordinates	28.433282, -80.583266		32.461092, -80.723941	
Unit Configuration	**Standard**	**Modified**	**Standard**	**Modified**
Refrigerant	R-410a		R-22	
Nominal Tons	8.5		20	
Expansion Type	TXV		Orifice	TXV
Evaporator Coil	4 row/15 fpi	5 row/14 fpi	4 row/15 fpi	4 row/16 fpi
Circuiting	Face split	Interlaced	Interlaced	Interlaced
Evaporator Face Area sqft	11.1	8.6	26.0	20.3
Face Velocity FPM	268	318	283	200
Performance				
Cooling Capacity Btuh	**96,998**	**96,400**	**249,880**	**242,164**
kW @ 95F ambient	8.05	7.60	23.7	20.7
SHR @ 81.5F ambient	0.72	0.65	0.72	0.74
SHR Decrease Percent	9.1%		-2.8%	
Average coil airflow CFM	2975	2731	7350	4064
Supply Air F	57.0	55.6	57.3	58.2
Average Duct Static in-wc	0.40	0.39	0.40	0.13
EER @ 95F ambient	12.2	12.7	10.6	11.7
IEER	**13.2**	**14.2**	**11.2**	**13.4**
Percent Increase IEER	7.3%		19.4%	

Figure 6.3-1 Comparison of factory ratings versus ClimaStat field measurements.

Comparative "with" versus "without" data sets with similar weather conditions were identified for further investigation to better quantify the improvements in performance.

6.3.1 MCASB Performance Comparisons

A summary of these data sets and their resulting output for MCASB are shown in Figure 6.3-3, which compares operating conditions and performance of the existing unit as found at Building 1283 at MCASB against ClimaStat retrofitted unit, and against the baseline unit that was refurbished with new parts and coil cleaning. Comparisons were performed against two baseline levels: (1) A mid-summer comparison of the refurbished, 8-year old Trane unit as the baseline

for evaluation of the ClimaStat retrofitted Trane unit, and (2) a shoulder-season comparison of the Trane unit after minor repairs were completed as a second baseline for evaluation of the ClimaStat retrofitted Trane unit. Conditions listed in the upper sections of Figure 6.3-3 demonstrate that the two data sets are comparable with respect to cooling load and space conditions, for example, similar average outdoor temperature for the period, similar indoor humidity, approximately equal degree-days, etc. The mid-summer comparison shows a 46.4% reduction in energy used per day, and the shoulder-season shows a 39.9% reduction in energy use per day. The measured IEER improvement between the refurbished baseline unit and the ClimaStat retrofitted unit is 29.2%, and the improvement between the "as found" unit and the refurbished, ClimaStat retrofitted unit is a 71.5% increase in energy efficiency. Unit cooling capacity was increased from about 17 tons to the full rated 20 tons, and peak kW demand was reduced by one-third from 30 kW to 21 kW.

MCASB TRANE Summary

FIELD TEST RESULTS	**South Carolina Site**			
Season	MID-SUMMER		SHOULDER	
Dates 2012	Jul 25-Aug 5	Aug 11-20	Apr 13-21	Oct 12-20
	Refurbished	**ClimaStat**	**Existing**	**ClimaStat**
Outdoors				
Average Outdoor F	84 °F	81 °F	67.8	71.9
High Outdoor F	95 °F	93 °F	82.4	91.4
Average Outdoor Dew Point	74 °F	72 °F	56.1	57 °F
Indoors				
Average Space F	74.1	74.6	77.0	73.6
Average Space Dew Point	60.3	60.1	53.5	53.6
Space Humidity Average	62%	61%	45%	50%
Energy				
Cooling Degree Days/day	24.1	22.9	9.5	9.3
Time in Comfort Zone	64%	65%	60%	67%
Ventilation OK	100%	100%	100%	100%
Energy kWh per day	297	159	175	105
Percent Decrease Energy	46.4%		39.9%	
Cooling Performance				
Cooling Capacity Btuh	194,450	242,879	207,584	242,164
kW @ 95F ambient	21.3	20.2	30.3	20.7
Operating SHR	0.86	0.72	0.76	0.74
Supply Air				
Average Coil Airflow CFM	8203	4837	7619	3809
Supply Air F	65.1	58.8	62.3	58.2
Average Coil Static in-wc	0.21	0.23	0.20	0.09
EER @ 95F ambient	9.11	12.0	6.8	11.7
IEER	**9.5**	**12.3**	**7.8**	**13.4**
Percent Increase IEER	29.2%		71.5%	

Figure 6.3-3 Comparison of operating conditions and performance at MCASB.

6.3.2 CCAFS Performance Comparisons

Performance comparisons for CCAFS were made between the baseline factory-new Carrier unit, and the ClimaStat unit for dry-season and humid-season data sets. Comparison of CCAFS data sets is not straightforward as with MCASB data sets, because the taxing requirement for precise humidity and temperature control adds a second and third dimension to the assessment. Results of the CCAFS comparisons are listed in Figure 6.3-4, which shows the operating conditions in the upper sections and the results in the lower half. Perhaps most significant to energy savings is the reduction in reheat energy usage from a substantial amount accounting for 20% of system energy use, to nearly eliminating the need for reheat. While providing this reheat energy reduction, the ClimaStat unit also showed a 27.2% increase in cooling energy efficiency during humid-season operation as detailed in Figure 6.3-4. Dry-season data did not show as significant an increase in cooling energy efficiency (7.5%) because the unit controls are configured for maximum dehumidification, which was done to minimize the use of reheat and overall system energy use. By suspending the goal of minimizing energy intensive reheat, in effect considering reheat energy use as external to the demonstration project for the purpose of predicting

CCAFS Carrier Summary

FIELD TEST RESULTS	Florida Site		
Season	Summer	Humid	Dry
Dates 2012	June 2-16	Oct 2-16	Dec 8-16
	Baseline	**ClimaStat**	**ClimaStat**
Outdoors			
Average Outdoor F	84 °F	80 °F	76 °F
High Outdoor F	93 °F	88 °F	82 °F
Average Outdoor Dew Point	71 °F	71 °F	66 °F
Indoors			
Average Space F	72.9	71.3	72.4
Average Space Dew Point	56.9	58.2	57.7
Space Humidity Average	57%	57%	60%
Energy			
Cooling Degree Days/day	18.8	14.8	5.5
Time in Comfort Zone	100%	81%	100%
Ventilation OK	98%	100%	100%
Reheat Energy kWh	**124.2**	**14.9**	**0.0**
Actual Field EER	12.9	15.9	15.4
Percent Increase EER	>	23.2%	19.2%
Cooling Performance			
Cooling Capacity Tons	7.3	8.7	9.0
Dehumidification Increase	**-3%**	**37%**	**75%**
Operating SHR	0.70	0.65	0.57
Supply Air			
Average Coil Airflow CFM	2922	3068	2219
Supply Air F	66.2	61.2	64.1
Average Coil Static in-wc	0.11	0.13	0.24
EER @ 95F ambient	11.3	14.6	12.0
IEER	12.5	15.9	13.4
Increase IEER vs Baseline	-5.3%	27.2%	7.5%

Figure 6.3-4 Comparison of operating conditions and performance at CCAFS.

performance under more typical conditions, and by widening the temperature deadband to allow longer compressor run cycles, the investigators hypothesize there will be a more consistent and substantial increase in IEER closer to what was measured at MCASB and predicted by the ORNL Mark 7 modeling.

Compressor operation is significantly cooler with ClimaStat technology installed as shown in Figure 6.3-5, which likely will result in longer compressor life as well as sustainability of improved efficiency. Figure 6.3-5 compares compressor operating conditions and refrigerant cycle efficiency of the baseline unit, April 13 thru August 5, against ClimaStat retrofitted unit, August 11 thru October 20, 2012. Compressor discharge superheat averaged 47 to 67 degrees-F cooler with ClimaStat relative to the baseline units. Compressor discharge temperatures were reduced from closer to 200F down to closer to 100F, depending on ambient conditions. Cycle efficiency, which includes only the work of compression and not fan motors or other parasitic equipment losses, was nearly doubled, indicating a good deal less energy waste in the compressor itself.

COMPRESSOR	MID-SUMMER		SHOULDER	
South Carolina Site	Jul 25-Aug 5	Aug 11-20	Apr 13-21	Oct 12-20
Average Discharge F	212	149	162	117
Discharge Superheat deg-F	104.8	38.0	67.9	20.2
Max Amps	27.9	28.2	25.7	23.3
Average Amps	21.0	23.2	20.5	17.5
Average High Side PSIG	221	232	209	188
Average Lift Ratio	4.2	3.4	3.0	3.2
Cycle Efficiency COP	1.9	4.6	2.3	5.3
Percent Increase COP	138.0%		133.5%	

Figure 6.3-5 Comparison of compressor conditions and refrigerant cycle efficiency.

6.4 FACILITY INDOOR AIR QUALITY

Indoor air quality was compared pre- and post- implementation of ClimaStat technology using three criteria: (1) predicted mean vote (PMV), (2) the comfort zone as defined by ASHRAE Standard 55, and (3) ventilation level as defined by ASHRAE Standard 62 using space carbon dioxide concentration versus ambient level. Overall comfort values maintained by the ClimaStat units are listed in Figure 6.4-1.

COMFORT CONDITIONS	CCAFS, FL	MCASB, SC
Space Occupancy	Laboratory	Retail
Temperture Setpoint	72	74
Humidity Setpoint	55-65%	50-60%
Median Space Temperature	71.3	74.0
Median Space Humidity	63.7%	49.1%
Median Space CO_2 ppm	418	406
Time in Comfort Zone	81%	67%
Time PMV Satisfied	99.9%	70.1%
Time Ventilation Adequate	100%	100%

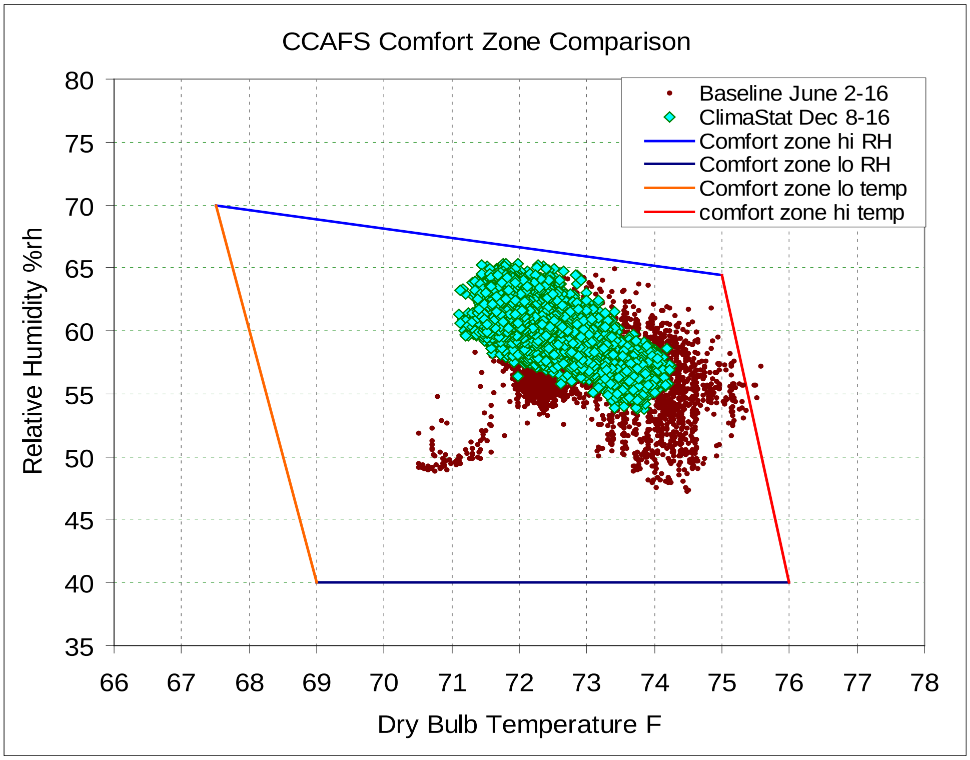
Figure 6.4-1 Comfort set points and measured values.

Sampling at 1-minute intervals of space temperature and humidity was used to calculate comfort level via predicted mean vote (PMV) analysis. The PMV is the average comfort vote, using a seven-point thermal sensation scale from cold (-3) to hot (+3), predicted by a theoretical index. Zero is the ideal value, representing thermal neutrality. The comfort zone is defined by the combinations of the six key factors for thermal comfort for which the PMV is within the recommended limits (-0.5<PMV<+0.5). The PMV model is calculated with the air temperature and mean radiant temperature along with the applicable metabolic rate, clothing insulation, air speed, and humidity. The values used in the analysis are as follows: bulk air velocity 30 fpm (as measured), clothing level 0.75 clo (somewhat more than trousers and a long-sleeve shirt), and activity level 1.35 met (filing, standing, or walking about). If the resulting PMV value generated by the model is within the recommended range, the conditions were deemed within the comfort zone.

Dissatisfaction with comfort level was less than 1% of the time: 0.5% warm and 0.4% cool, as listed in Figure 6.4-1 at CCAFS. Temperature and humidity were in the ASHRAE Standard 55 defined comfort zone 81% of the time, as plotted in Figure 6.4-2 for CCAFS and MCASB. The plots of Figures 6.4-3a and 6.4-3b show the comfort zone outline, and compare values of temperature and relative humidity from baseline data sets versus ClimaStat data sets. Ventilation was acceptable according to ASHRAE Standard 62 defined CO_2 level 100% of the time.

Dissatisfaction with comfort level by PMV was less than 29.9% of the time at MCASB, mostly too warm as expected with a night temperature setpoint of 80F (26.7 F) for 8 hours each day while the Exchange was closed (data was not tagged for occupancy). Temperature and humidity were in the ASHRAE Standard 55 defined comfort zone 67% of the time. Ventilation was acceptable according to ASHRAE Standard 62 defined CO_2 level 100% of the time. Median temperature was 74.0 F (23.3) and median humidity was 49.1% as measured in the space with

calibrated sensors. The investigators concluded the existing IAQ was excellent and there was no significant change in comfort or ventilation pre- and post- technology implementation.



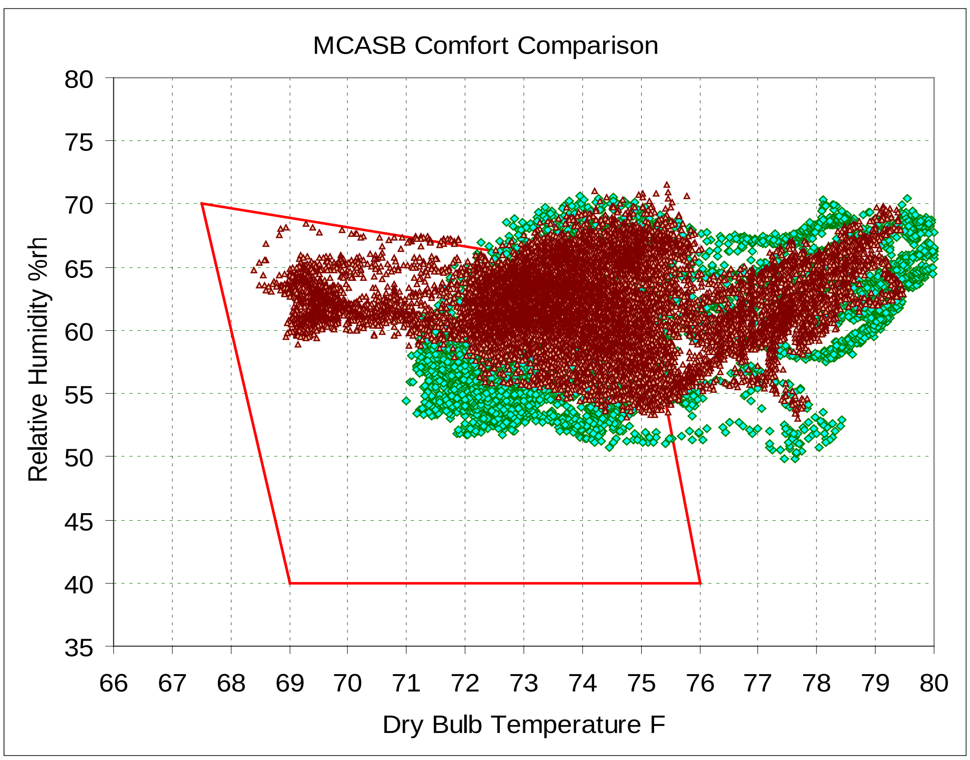


Figure 6.4-2 a(CCAFS) and b(MCASB) ASHRAE Standard 55 Comfort Zone data.

7 COST ASSESSMENT

7.1 FACTORS AFFECTING ECONOMICS

Based on bench scale testing and limited field testing of ClimaStat completed during 2002 – 2009, the ESTCP demonstrations at MCASB and CCAFS were expected to demonstrate the technology is cost effective, based on reduction in space cooling energy costs. The two cost assessment scenarios, 1) retrofit of existing unitary A/C equipment at MCASB, and 2) modification of new unitary A/C equipment at CCAFS, were addressed using cost and energy savings data collected during the demonstration project period.

Cost and savings data was input to life cycle cost analysis using BLCC 5.3-12 software developed by NIST (National Institute of Standards) for DOE's Federal Energy Management Program (FEMP). The investigators used the Milcon: ECIP template in the BLCC software and ECIP reports were generated for both ClimaStat demonstrations using data collected during the demonstration projects. The ECIP reports for both 10- and 20-year BLCC assessments are included in the Appendices.

ClimaStat technology is well suited to DoD Performance Contracting efforts to reduce facility operating costs. The demonstration of ClimaStat technology, both as a retrofit to existing unitary systems and as an enhancement to new equipment, provides a solid basis for technology deployment at all DoD facilities with unitary DX equipment and significant cooling loads. The extent of economic benefit of performance improvements depends on the following three factors:

1. *IEER of retrofit vs. new OEM equipment*: The Integrated Energy Efficiency Ratio (IEER) of currently installed unitary DX equipment is typically lower than new equipment of similar capacity. For example, *Efficiency* Maine suggests assuming an EER of 9.0 for equipment 5-10 years old, and 8.0 for systems 10-15 years old. Raising the energy performance of new rooftop unitary A/C equipment has been considered for several years, but the minimum required EER for new equipment remains under 9.0. A new standard of EER 11.0 has been proposed to the U.S. Department of Energy (DOE) during rule-making on energy efficiency standards for commercial unitary DX equipment, with a recommended adoption date of January 1, 2010. However, this new standard has not yet been adopted, so new unitary systems are assumed to have an EER of 10.1, based on DOE guidance.[21] For purposes of the BLCC analyses below, collected operational data were used to calculate the EER values given in Table 7.1-1 for the demonstration units at MCAS Beaufort and CCAFS.

2. *Capital cost of retrofit vs. new OEM equipment*: In the proposal for this ESTCP project, retrofit of existing unitary equipment was assumed to have a capital cost of $380/ton of capacity, while adding ClimaStat to new unitary equipment was assumed to have a capital cost of $112/ton of capacity.[22] The difference in cost stems from the design and installation work necessary for field retrofit of existing equipment, while a factory-installed ClimaStat system would be a repeatable design and installation of components that are commonly used

[21] *Recovery Act: Advanced Energy Efficient Building Technologies*, Funding Opportunity Number DE-FOA-0000115, U.S. Dept. of Energy, issued 6/29/2009, Attachment A "Guide for Evaluation of Energy Savings Potential," Table D.
[22] Advantek cost estimates for proposal in response to DE-FOA-0000115.

in unitary DX manufacture. For comparison, the cost of replacement equipment averages $620 per ton plus about $400 per ton for installation – a total replacement cost of around $1,000 per ton. Incremental cost ranges from 20% to factory-equip a new 8-ton unit with ClimaStat to 50% of the cost of a new unit for refurbishment / retrofit of an existing 20-ton unit. ClimaStat cost per ton drops significantly as system size increases for example, the cost per ton for retrofit of a 20-ton unit is about one-third that of a 5-ton unit. Also, electric utilities may provide incentives for purchase of new equipment that is significantly more efficient than standard equipment. For example, the Pepco Industrial & Commercial Energy Efficiency Incentive Program offers incentives of $35 - $70/ton of capacity for new unitary high-EER HVAC units.[23] For the purposes of the demonstration, no utility incentives are assumed.

3. *Ratio of sensible and latent cooling loads*: ClimaStat adds an active humidity control function to unitary DX systems, resulting in improved comfort in hot and humid climates. In arid climates where humidity control is not as important, ClimaStat will provide even greater energy efficiency. Existing unitary equipment, such as the MCASB demonstration unit, does not compensate for increased latent loads during periods of lower sensible loads, and this can result in buildup of space relative humidity. The 20-ton RTU that was retrofitted with ClimaStat utilizes two compressors for energy efficiency. At partial sensible load operation, one compressor is taken offline by the thermostat control, while the full evaporator coil is still used for cooling. As a result, discharge temperature from the evaporator coil goes up and dehumidification capacity is decreased, resulting in higher, possibly unacceptable, relative humidity levels in the conditioned space. The ClimaStat retrofit to this unit provides greater dehumidification during periods of lower sensible loads. The economic benefit of improved humidity control is estimated by assuming ClimaStat replaces the standard factory hot-gas reheat option for unitary systems. For example, Trane offers a humidity control option on its new unitary equipment that adds $1,500 to the cost of a 20-ton unit. Throughout the projects at MCASB and CCAFS, relative humidity and CO2 readings were continuously collected in the spaces conditioned by the demonstration equipment.

7.2 ECONOMIC EVALUATION OF MCAS BEAUFORT DEMONSTRATION

RTU-2 serving Building 1283 at MCAS Beaufort is a 2003 20-ton Trane Voyager rooftop unit that was installed when the Base Exchange was built. The ESTCP project was started in March 2011 and RTU-2 was initially serviced by a local A/C service company in June 2011. During the initial inspection/servicing, one of the condenser fan motors on RTU-2 was found to be inoperative and was subsequently replaced by the MCASB O&M contractor. The outside air damper was also found to be inoperative, but was not repaired at the time. Instrumentation and data loggers were installed on RTU-2 in June & July 2011 and data collected continuously thereafter. Table 7.2-1 presents the RTU-2 service record from the start of the ESTCP contract until the ClimaStat modification was made in August 2012. RTU-2 required much more service to bring it up to a credible baseline operation than we had anticipated, attesting to the common problem of commercial rooftop A/C equipment operating at less than peak energy efficiency.

[23] https://cienergyefficiency.pepco.com/Documents/Pepco%20HVAC%20Form.pdf, "Unitary HVAC Incentives Application", 09/04/2009 v2.

Building 1283 RTU-2 Service History

Date	***Provider***	***Service Performed***	***Cost/Source***
Jun-11	Beaufort Air	Initial inspection & servicing; found condenser fan motor and OA damper inoperative	$1,435
Jul-11	Advantek	Installed sensors in conditioned space and on RTU-2	ESTCP
Jul-11	ATSI	Replaced condenser fan motor	Base O&M
Jul-11	Beaufort Air	Added R-22 refrigerant and looked for leak	$100
Oct-11	ASRS	Found bad compressor and recharged both circuits	$1,699
Dec-11	Coastal Air	Replaced compressor; found restriction in one circuit	$3,050
Mar-12	Coastal Air	Replaced replacement compressor under warranty	-
Apr-12	Trane	Service, diagnostics & recommended repairs	$4,735
May-12	ATSI	Replaced condenser fan & motor	Base O&M
Jun-12	Trane	Repairs on unit	$2,154
Jul-12	Trane	Repairs on unit	$1,175
Aug-12	Trane	Assist Advantek with ClimaStat modifications to unit	$7,327

Table 7.2-1 Service History for RTU-2 @ MCAS Beaufort

The ClimaStat modifications to RTU-2 involved:

- ❑ Replacing cooling coil
- ❑ Adding bypass damper at cooling coil
- ❑ Add accumulator/heat exchanger unit in liquid R22 line
- ❑ Add additional controls for enhanced dehumidification
- ❑ Exchange blower motor and add variable frequency drive

Total project cost for ClimaStat modifications, including all materials, labor, installation and testing, was $13,887, which represents $694/ton for the 20-ton Trane unit. However, all ClimaStat parts for this demonstration unit were special order and ordering in quantity and from wholesalers are expected to reduce costs. Also, an experienced field installation crew familiar with ClimaStat would reduce labor costs, as would a unit in better condition. We believe the repeatable cost of regular ClimaStat field installations would bring the cost down to $400/ton, which is close to the $380/ton mentioned earlier in this section for a 20-ton dual-compressor unit.

For performing a BLCC analysis of the ClimaStat retrofit at MCASB, the following cost elements are assumed:

1. The 20-ton RTU-2 on MCASB Building 1283 operates in a climate with 3,787 Cooling Degree Days (CDD).[24]
2. From operational data logged at demonstration, cooling requirement is 265,182 Btu per CDD, and annual cooling load is 1,004,244,234 Btu.
3. From operational data, baseline IEER of RTU-2 is 9.5 Btu/watt-hour, and IEER of RTU-2 with ClimaStat is 12.9 Btu/watt-hour.

[24] CDD is 2012 total from calculator at http://www.degreedays.net , MCAS Beaufort weather station, 60º F base.

4. Annual energy for baseline operation is 105,710 kWh; annual energy for ClimaStat modified operation is 77,848 kWh.
5. The price of retrofitting RTU-2 with ClimaStat is $450/ton, for a total cost of $9,000.
6. The 2012 cost of electricity at MCASB is $0.08/kWh.

Using these assumptions, the BLCC 5.3 – 12 software generated the Milcon: ECIP report (full reports in Appendices) data presented in Table 7.2-2 for the MCASB demonstration of ClimaStat retrofit at MCASB.

	Simple Payback (years)	Savings to Investment Ratio (SIR)	Adjusted Internal Rate of Return (AIRR)
MCASB retrofit – 10 yr	**4.04**	**2.17**	**11.33%**
MCASB retrofit – 20 yr	**4.04**	**3.79**	**10.10%**

Table 7.2-2 BLCC Analysis for MCASB ClimaStat Retrofit.

The cost/benefit of ClimaStat add-on to RTU-2 is better than expected, due to a greater increase in efficiency, a higher cooling load, and consequent higher energy savings. If RTU-2 is a typical example of rooftop A/C equipment used in military and other federal buildings, this ESTCP demonstration has also highlighted the issue of declining energy performance over the life of this type equipment. If the BLCC analysis had been performed using the “as found” IEER of RTU-2, the energy savings resulting from the ClimaStat retrofit would have been 39.5%, instead of the 26.5% savings after extensive work to bring RTU-2 to an acceptable baseline.

7.3 ECONOMIC EVALUATION OF CCAFS DEMONSTRATION

As a demonstration platform for ClimaStat at CCAFS, energy management personnel selected a packaged A/C unit slated to be replaced at Building 1115. This unit serves the Engineering Development Laboratory (EDL) of the Naval Ordnance Test Unit (NOTU), and provides precise temperature and humidity control for the laboratory environment. The 7.5-ton Trane package unit installed new in 1999 was slated for replacement due to the low energy efficiency and advanced deterioration from operation in a hot, humid coastal location. Carrier Corporation was approached about donating a new unit to replace the Trane equipment and Carrier agreed to provide, at no cost, an 8.5-ton high efficiency unit with humidity control capability. The new Carrier unit uses R-410a refrigerant and 2011 OEM technology, in contrast to the c.2003 MCASB demonstration unit, which uses legacy R-22 refrigerant that is obsolete by today’s regulations.

The Carrier unit was installed in January 2012 and baseline energy use data was collected until the ClimaStat modifications were made in August 2012. Thereafter the performance was monitored to determine changes from baseline operation. Unlike the MCASB demonstration, where a 9-year old unit required extensive work to bring it to a credible baseline operation, the

CCAFS unit was new and immediately provided an acceptable baseline for comparison with the ClimaStat-equipped unit. Also, the cost basis for the CCAFS demonstration was clearer than with the retrofit situation at MCASB, since the manufacturer could provide an un-depreciated cost for the new Carrier unit.

The ClimaStat modifications to the new Carrier unit at CCAFS involved:

- ❑ Replacing cooling coil
- ❑ Adding bypass damper at cooling coil
- ❑ Add accumulator/heat exchanger unit in liquid R-410a line
- ❑ Add additional controls for enhanced dehumidification
- ❑ Exchange single speed blower motor and add variable frequency drive

Total project cost for CCAFS ClimaStat modifications, including all materials, labor, installation and testing, was $9,190, which represents $1,081/ton for the 8.5-ton Carrier unit. Similar to the modification of the demonstration equipment at MCASB, the CCAFS ClimaStat modification was field-performed with special order parts, rather than a true factory installation where assembly –line economies of scale greatly benefit product cost. Based on actual component and equipment costs, we believe that providing ClimaStat as a factory-installed option would greatly reduce the cost to about $120 per ton for an 8.5 ton dual-compressor unit.

For performing a BLCC analysis of the ClimaStat modification of the CCAFS unit, the following cost elements are assumed:

1. The 8.5-ton Carrier unit at CCAFS Hangar Y operates in a climate with 3,630 Cooling Degree Days (CDD).[25]
2. From operational data logged at demonstration, cooling requirement is 99,340 Btu per CDD, and annual cooling load is 360,604,200 Btu.
3. From operational data, baseline IEER of the Carrier unit is 12.5 Btu/watt-hour (Carrier catalog gives unit IEER of 13.2 Btu/watt-hour), and IEER of the unit with ClimaStat is 14.7 Btu/watt-hour.
4. Annual energy for baseline cooling is 28,848 kWh and annual energy for dehumidification with electric reheat is 4,159 kWh, for a total energy use of 33,007 kWh/year.
5. Annual energy for ClimaStat modified cooling operation is 24,531 kWh and annual energy for dehumidification is 389 kWh, for a total energy use of 24,920 kWh/year.
6. The price of adding ClimaStat to the 8.5-ton Carrier unit at the factory is $200/ton, for a cost of $1,700 as a factory-installed option.
7. The 2012 cost of electricity at CCAFS is $0.08/kWh.

Using the above boundary conditions, the BLCC 5.3 – 12 software analyzed project economics and generated the Milcon: ECIP report (full reports in Appendices) data presented in Table 7.3-1 for the CCAFS demonstration of adding ClimaStat to the new Carrier unit.

[25] CDD is 2012 total from calculator at http://www.degreedays.net , CCAFS weather station, 64º F base.

	Simple Payback (years)	Savings to Investment Ratio (SIR)	Adjusted Internal Rate of Return (AIRR)
CCAFS retrofit – 10 yr	2.63	3.31	16.11%
CCAFS retrofit – 20 yr	2.63	5.78	12.44%

Table 7.3-1 BLCC Analysis for CCAFS ClimaStat Upgrade.

8 IMPLEMENTATION ISSUES

The ClimaStat modifications to the demonstration units were accomplished with relatively few technical or implementation problems. This section describes the issues that had some bearing on technology performance or project implementation, both before and after ClimaStat modifications were made.

8.1 TECHNOLOGY APPLICATION ISSUES

1. Modification of existing equipment at MCASB – As previously indicated, using equipment that had been operating for a number of years proved to present unexpected problems in establishing a credible baseline operation and energy efficiency. The existing equipment that had drifted significantly from factory specifications. As a result, we spent much time and funds to bring the MCASB unit up to a credible baseline operating condition. We contracted with five different service technicians to work on the unit until we found a very competent Trane factory service technician, who put the equipment in good working order, and we were able to collect credible operating data. We used the same technician to perform the ClimaStat modifications of the equipment, however this high level of expertise severely impacted installation costs.

2. Performing ClimaStat modification during period of peak cooling demand – ClimaStat was installed on operating A/C equipment at both sites during August 2012, the peak cooling season for both sites. Consequently, we had to provide auxiliary cooling for the conditioned spaces, since both buildings involved remained in service throughout the modifications. During the ClimaStat installations, we kept in close touch with the manager of the operations in the conditioned space and also worked during hours the spaces were closed to minimize the impact of losing the A/C units involved.

3. Coordination with occupants and managers of buildings involved in the demonstration – We found it was critical to maintain close communication with the occupants of the buildings involved in the ClimaStat demonstrations. The internet-based DAQ monitoring allowed us to identify conditions and trends in space temperature, relative humidity, CO2 levels, and equipment status. In the event we realized there was a problem, such as when the compressor burned out in the MCASB demonstration unit, we were able to quickly notify MCASB personnel who respond to A/C service outage, as well as work with onsite managers to resolve the problems.

4. Reconciling DAQ installed with existing building A/C control systems – DDC control/monitoring systems are common on DoD installations and when a project involves installation and use of a separate control system, it's important to coordinate readings from the DAQ with the DDC system. In some cases, the DAQ system will identify previously undetected problems with DDC controls and/or sensors.

5. Harmonic line noise emitted by blower variable frequency drive –EDL staff at CCAFS use sensitive electronic instruments in the course of their testing and calibration work.

They noticed a background level of electronic noise in their equipment, which after investigation, was found to be emanating from the variable frequency drive used to control blower speed in the ClimaStat unit. The drive is a low-cost micro-drive, which has been used without issues at many other sites. A low pass filter was installed on the control input as detailed in Figure 8.1-1, and a factory RF line filter was installed onto the control board that will suppress line noise as shown in Figure 8.1-2. The line filter suppressed electrical interference to within acceptable levels as determined by the CE Council Directive 89/336/EEC relating to the Class A Industrial Standard, and the staff confirmed that the electronic noise was no longer present.

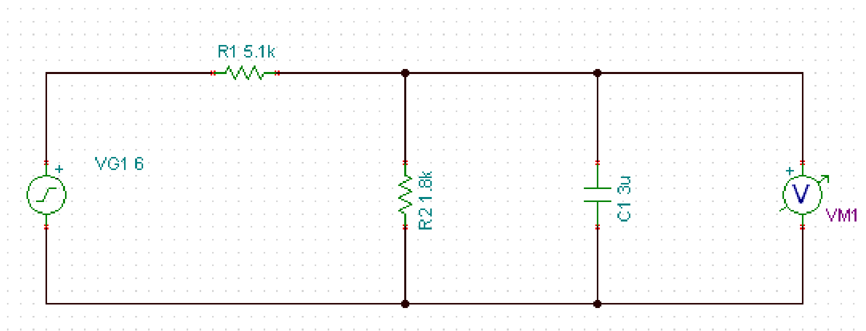


Figure 8.1-1 Low pass filter for harmonic noise suppression used on VFD at CCAFS.

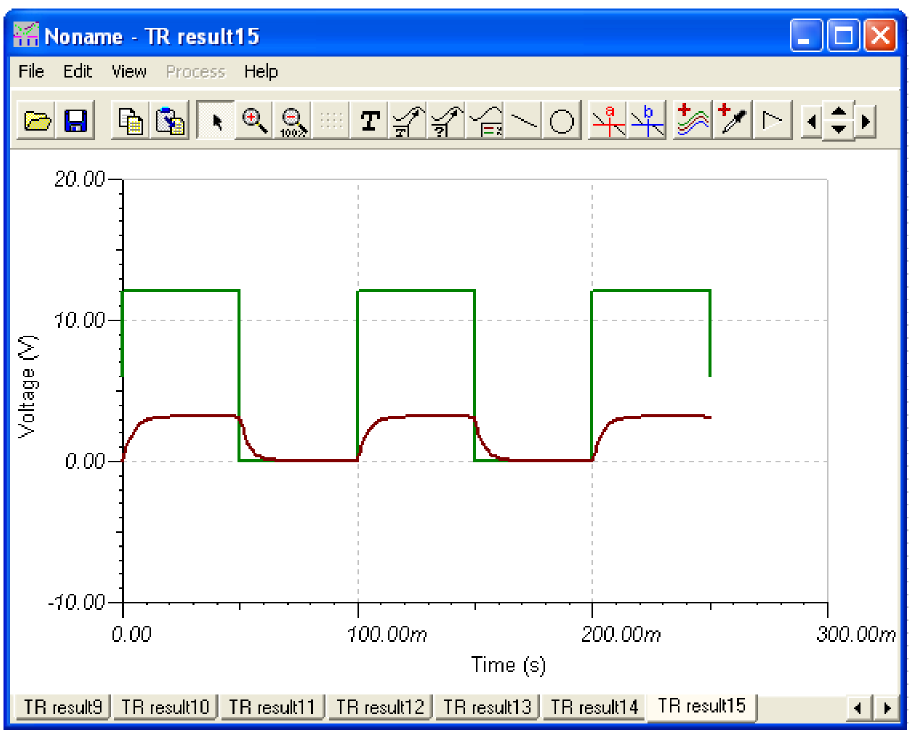


Figure 8.1-2 Spice simulation of RC noise suppression circuit with 10Hz signal injected.

6. Two-position versus modulating bypass damper actuator – There is an inherent cost versus performance tradeoff between controlling the position of the bypass damper with a two-position, open/close actuator as was installed in the Carrier unit at CCAFS (the lower cost alternate), versus the modulating variable position actuator as was installed in the Trane unit at MCASB. The reduced control resolution impacted efficiency by a small degree. The modulating actuator is preferred if the added cost is not high enough to significantly diminish overall technology economics.

7. Control requirements of the conditioned space – The precise temperature and humidity tolerances of the EDL at CCAFS are atypical of DoD and commercial applications. Maintaining tight control over temperature and humidity caused the compressors to short cycle: 6 to 12 minute cycles were typical as shown in Figure 8.1-3, compared with the 20 minutes to hours-long cycles at MCASB that is typical of most installations. It is well known that short cycling reduces energy efficiency in package units, which typically require several minutes of uninterrupted compressor operation for conditions to stabilize. The ClimaStat modifications increase the thermal mass and capacity of the refrigeration system, so efficiency is affected when the compressor short-cycles.

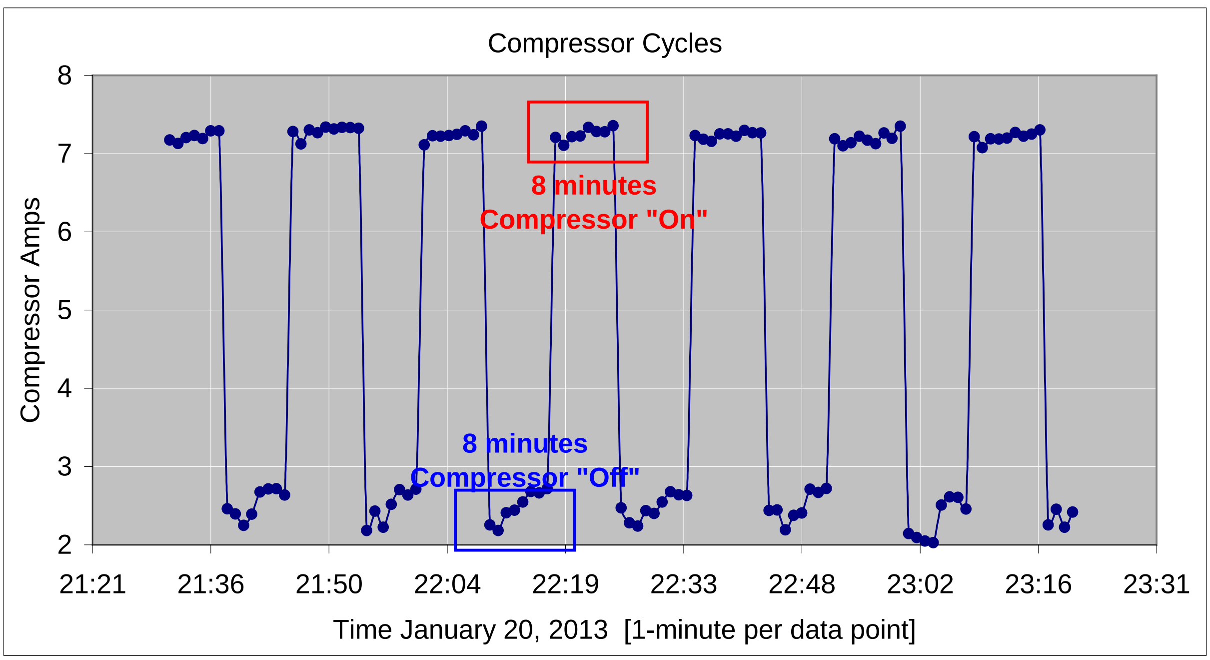


Figure 8.1-3 Plot of compressor-1 amp data from Carrier unit showing short cycle times.

8.2 PERFORMANCE MONITORING ISSUES

1. Instrumentation of demonstration equipment for data collection – Collection of temperature and pressure data at several points in the refrigerant cycle was deemed critical for defining thermodynamic states of the refrigerants and their performance in cooling air. While conventional unitary air conditioners are equipped with ports and valves that allow service technicians to monitor refrigerants, the demonstration units required additional ports in the recirculating refrigerant lines, which required the refrigerant be evacuated, new ports installed, and refrigerant recharged into the system.

   We encountered more difficulties in instrumenting the MCASB demonstration unit than we did with the CCAFS demonstration unit, because it was a 9-year old system that had drifted from factory specs, and this introduced unknowns into the assumptions made in designing and installing the DAQ system. For example, the labeling of the two refrigerant circuits had been reversed, and some but not all of the controls reversed again. Also, when one of the pressure sensors developed a refrigerant leak and one circuit lost its R22 charge, the safety switch for that compressor cutoff at low refrigerant pressure didn't work, because it was connected to the other circuit, and the compressor in that circuit failed and had to be replaced.

   Another problem with the DAQ system was availability of sensors that would provide continuous collection of accurate and repeatable data. For example, we used new rotary flow meters to measure the flow rate of liquid refrigerants in both demonstration units, and these initially didn't work satisfactorily. We spent much time and budget investigating and resolving these flow meter problems. Only after extensive consultation with the flow meter manufacturer and making modifications to the meters, we were able to collect data we needed for performance evaluation.

2. Selecting data sets to use for comparative performance modeling – Determining IEER from baseline and modified demonstration equipment requires careful consideration of operation time and conditions. For example, ambient air temperatures in which the condenser operates significantly affect cooling capacity and compressor energy use. We present IEER values for a range of operating conditions, including ambient air temperature; cooling demand of conditioned space; temperature & relative humidity of the conditioned space; and CO2 levels of the space, which reflect the demand for outside air ventilation. It's critical to present comparable operational states for both baseline and modified equipment operation, as defined by these variables, to provide credible evaluation of the add-on technology.

3. Obtaining internet service onsite for monitoring and download of logger data – The DAQ installed at both sites required a reliable internet connection for near real-time data collection and system monitoring. This arrangement allowed us to remotely track operation of the demonstration units and alert us to problems in the facilities served by the units. At both sites we had to install and pay for monthly service of dedicated internet connections that were completely separate from the secure and EMCS networks at the DoD installations.

9 REFERENCES

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10 APPENDICES

Appendix A: Points of Contact

POINT OF CONTACT Name	ORGANIZATION	Phone E-mail	Role in Project
Michael West	Advantek Consulting	321-733-1426 x3 mwest@advantekinc.com	Principal Investigator
Richard Combes	Advantek Consulting	321-733-1426 x5 Rrch.combes@advantekinc.com	Principal Investigator
John Adams	Advantek Consulting	321-733-1426 x6 John.adams@advantekinc.com	Mechanical Engineer
Neil Tisdale	MCASB Public Works	843-228-6317 belton.tisdale@usmc.mil	MCASB Energy Manager
Bill Rogers	MCASB Facilities	843-228-7118 william.t.rogers2@usmc.mil	MCASB Utilities Engineer
Kevin Riley	CCAFS AFSPC IOMS	321-476-3721 kevin.riley.5.ctr@us.af.mil	CCAFS Energy Manager
Chris Cook	45th Space Wing	321-853-9719 ccook@cci-alliance.com	Resource Efficiency Manager

Appendix B: BLCC ECIP reports for Cost Assessment of ClimaStat Demonstrations

1. **MCAS Beaufort, SC – 10 year economic life**

NIST BLCC 5.3-12: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2012.
Location: South Carolina Discount Rate: 3%
Project Title: MCAS 10 yr Analyst: RSC
Base Date: August 1, 2012 Preparation Date: Wed Jan 30 14:23:46 EST 2013
BOD: August 1, 2012 Economic Life: 10 years 0 months
File Name:
1. Investment
Construction Cost $9,000
SIOH $0
Design Cost $0
Total Cost $9,000
Salvage Value of Existing Equipment $0
Public Utility Company $0
Total Investment $9,000
2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings
Item Unit Cost Usage Savings Annual Savings Discount Factor Discounted Savings
Electricity $23.44569 95.1 MBtu $2,229 8.782 $19,574
Energy Subtotal 95.1 MBtu $2,229 $19,574
Water Subtotal 0.0 Mgal $0 $0
Total $2,229 $19,574
3. Non-Energy Savings (+) or Cost (-)
Item Savings/Cost Occurrence Discount Factor Discounted Savings/Cost
Non-Annually Recurring
Non-Annually Recurring Subtotal $0 $0
Total $0 $0
4. First year savings $2,229
5. Simple Payback Period (in years) 4.04 (total investment/first-year savings)
6. Total Discounted Operational Savings $19,574
7. Savings to Investment Ratio (SIR) 2.17 (total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR) 11.33% (1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

2. MCAS Beaufort, SC – 20 year economic life

NIST BLCC 5.3-12: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2012.
Location: South Carolina Discount Rate: 3%
Project Title: MCAS 20 yr Analyst: RSC
Base Date: August 1, 2012 Preparation Date: Wed Jan 30 14:26:59 EST 2013
BOD: August 1, 2012 Economic Life: 20 years 0 months
File Name:
1. Investment
Construction Cost $9,000
SIOH $0
Design Cost $0
Total Cost $9,000
Salvage Value of Existing Equipment $0
Public Utility Company $0
Total Investment $9,000
2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings
Item Unit Cost Usage Savings Annual Savings Discount Factor Discounted Savings
Electricity $23.44569 95.1 MBtu $2,229 15.310 $34,124
Energy Subtotal 95.1 MBtu $2,229 $34,124
Water Subtotal 0.0 Mgal $0 $0
Total $2,229 $34,124
3. Non-Energy Savings (+) or Cost (-)
Item Savings/Cost Occurrence Discount Factor Discounted Savings/Cost
Non-Annually Recurring
Non-Annually Recurring Subtotal $0 $0
Total $0 $0
4. First year savings $2,229
5. Simple Payback Period (in years) 4.04 (total investment/first-year savings)
6. Total Discounted Operational Savings $34,124
7. Savings to Investment Ratio (SIR) 3.79
(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR) 10.10%
(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

3. <u>CCAFS Cape Canaveral, FL – 10 year economic life</u>

NIST BLCC 5.3-12: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2012.
Location: Florida Discount Rate: 3%
Project Title: CCAFS 10 year Analyst: RSC
Base Date: August 1, 2012 Preparation Date: Mon Feb 04 12:01:24 EST 2013
BOD: August 1, 2012 Economic Life: 10 years 0 months
File Name:
1. Investment
Construction Cost $1,700
SIOH $0
Design Cost $0
Total Cost $1,700
Salvage Value of Existing Equipment $0
Public Utility Company $0
Total Investment $1,700
2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings
Item Unit Cost Usage Savings Annual Savings Discount Factor Discounted Savings
Electricity $23.44569 27.6 MBtu $647 8.703 $5,631
Energy Subtotal 27.6 MBtu $647 $5,631
Water Subtotal 0.0 Mgal $0 $0
Total $647 $5,631
3. Non-Energy Savings (+) or Cost (-)
Item Savings/Cost Occurrence Discount Factor Discounted Savings/Cost
Non-Annually Recurring
Non-Annually Recurring Subtotal $0 $0
Total $0 $0
4. First year savings $647
5. Simple Payback Period (in years) 2.63 (total investment/first-year savings)
6. Total Discounted Operational Savings $5,631
7. Savings to Investment Ratio (SIR) 3.31
(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR) 16.11%
(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

4. CCAFS Cape Canaveral, FL – 20 year economic life

NIST BLCC 5.3-12: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A
The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2012.
Location: Florida Discount Rate: 3%
Project Title: CCAFS 20 year Analyst: RSC
Base Date: August 1, 2012 Preparation Date: Mon Feb 04 12:03:37 EST 2013
BOD: August 1, 2012 Economic Life: 20 years 0 months
File Name:

1. Investment

Construction Cost $1,700
SIOH $0
Design Cost $0
Total Cost $1,700
Salvage Value of Existing Equipment $0
Public Utility Company $0
Total Investment $1,700

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item Unit Cost Usage Savings Annual Savings Discount Factor Discounted Savings
Electricity $23.44569 27.6 MBtu $647 15.179 $9,821
Energy Subtotal 27.6 MBtu $647 $9,821
Water Subtotal 0.0 Mgal $0 $0
Total $647 $9,821

3. Non-Energy Savings (+) or Cost (-)

Item Savings/Cost Occurrence Discount Factor Discounted Savings/Cost
Non-Annually Recurring
Non-Annually Recurring Subtotal $0 $0
Total $0 $0

4. First year savings $647

5. Simple Payback Period (in years) 2.63 (total investment/first-year savings)

6. Total Discounted Operational Savings $9,821

7. Savings to Investment Ratio (SIR) 5.78
(total discounted operational savings/total investment)

8. Adjusted Internal Rate of Return (AIRR) 12.44%
(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Appendix C: Impacts of Deferred Maintenance on DoD RTUs and Recommended Mitigation Strategies

Michael West, PhD, PE and **Richard Combes, PE, PhD**[26]

Advantek Consulting Engineering, April 2013

DoD ESTCP EW-201144

When the ability to provide heating, ventilation, and air conditioning (HVAC) basics – a functional, environmentally controlled facility - is diminished, so is the priority of preventive maintenance. In recent years, this condition of deteriorating facilities brought on by inadequate funding has frequently been referred to as "deferred maintenance." Deferred maintenance can be defined in terms of the accumulating capital maintenance that is not being accomplished and is therefore deferred. This white paper discusses the impacts of deferred, improper or neglected maintenance on Department of Defense (DoD) rooftop HVAC units (RTUs) and the approximate scale of the impact, and recommends mitigation strategies. It is based on intensive and detailed analysis of a single 20-ton rooftop package unit installed at a DoD site in 2003 and subsequently monitored / evaluated from 2010 through 2012 under DoD's Environmental Security Technology Certification Program (ESTCP) project EW-201144.

INTRODUCTION

Commercial unitary HVAC systems are estimated to consume 0.74 quads of energy annually in the U.S., or about 54% of commercial building cooling primary energy consumption, and are used to cool about 50% of all commercial space. Unitary DX split-system and package air conditioners are ubiquitous in DoD facilities and portable environmental control units (ECUs). Unitary HVAC systems are readily available in a wide range of capacities from 2 to 100-tons, have a low first cost, and are easily serviced. Military installations utilize unitary HVAC systems for space conditioning in buildings such as commissaries, schools, and theaters, and in field cooling systems used for mobile operations. Current code-required energy efficiency minimums for new unitary air conditioning and heat pump systems establish Energy Efficiency Ratios (EER) of 9.7 to 14.0 depending on system capacity. However, the substantial base of installed unitary systems has an EER of 9.0 or less, dependent on system condition and maintenance history.

[26] Michael West, PhD, PE is Principal-CEO with Advantek in Melbourne, FL. Richard Combes, PE is Senior Energy Engineer with Advantek in Beaufort, SC. Combined, they have over 50 years of energy efficiency and HVAC application, commissioning and R&D experience.

An ESTCP demonstration at Marine Corps Air Station – Beaufort (MCASB), located in Beaufort County, South Carolina, near the northern boundary of the DOE-designated Hot & Humid climate zone, provided insights into the impacts of deferred RTU maintenance. RTU-2 is a 2003 Trane Voyager unit serving Building 1283, the MCASB Base Exchange. The R-22, dual circuit, 20-ton (70.1 kW) 11.2 IPLV rooftop unit was instrumented with 45 sensors and web-communicating data loggers in 2010 to closely monitor operation and performance, available at (www.tinyurl.com/MCAS-Trane).

Figure 1 *RTU-2 on roof of MCASB 1283.*

Construction of Building 1283 was completed in 2003, and all the air conditioning units were installed new as part of the construction. Building 1283 is connected to a base-wide direct digital control (DDC) network, which monitors operational conditions continuously, including the status of RTU-2. Occupied hours are Monday through Friday: 0600 – 2300, Saturday: 0800 – 2300, and Sunday: 0800 – 2200. Air-conditioning this building is very similar to a stand-alone "big box" retail store, with staff and customers using the space from 15 – 17 hours every day of the week, excepting holidays. The Exchange is a large, open retail space with high ceilings, and is subject to frequent door openings, which provide uncontrolled, but effective, fresh air ventilation. There are also significant heat loads from lighting, influx of customers, electronics merchandise and refrigerated display cases.

FINDINGS

Building 1283 RTU-2 Service History

Date	*Provider*	*Service Performed*	*Cost/Source*
Jun-11	Beaufort Air	Initial inspection & servicing; found condenser fan motor and OA damper inoperative	$1,435
Jul-11	Advantek	Installed sensors in conditioned space and on RTU-2	ESTCP
Jul-11	ATSI	Replaced condenser fan motor	Base O&M
Jul-11	Beaufort Air	Added R-22 refrigerant and looked for leak	$100
Oct-11	ASRS	Found bad compressor and recharged both circuits	$1,699
Dec-11	Coastal Air	Replaced compressor; found restriction in one circuit	$3,050
Mar-12	Coastal Air	Replaced replacement compressor under warranty	-
Apr-12	Trane	Service, diagnostics & recommended repairs	$4,735
May-12	ATSI	Replaced condenser fan & motor	Base O&M
Jun-12	Trane	Repairs on unit	$2,154
Jul-12	Trane	Repairs on unit	$1,175
Aug-12	Trane	Assist Advantek with ClimaStat modifications to unit	$7,327

Table 1 *Service history of RTU 2*

RTU-2 required much more attention to bring it up to a credible baseline operation than anticipated, attesting to the widespread problem of commercial rooftop air-conditioning equipment operating at less than rated energy efficiency due to deferred maintenance. The performance of RTU-2 had drifted drastically from factory specifications. As a result, significant time and funds had to be expended to bring the unit up to a credible baseline operating condition. Table 1 presents the RTU-2 service record from 2011 until August 2012. We contracted with five different service companies to work on the unit until we found a very competent Trane factory service technician, who finally put the equipment in good working order. The technician corrected sensor wiring and switched circuits; replaced one compressor; replaced two fan motors; replaced both liquid line driers twice; removed clogged suction line filters; flushed circuits; adjusted and fine tuned the refrigerant charge; tested the compressor oil for acid and moisture; and cleaned the condenser and evaporator coils. The electrical / controls wiring had been modified over the years from its original configuration as various service technicians rushed to work around and bypass emergency problems. Note the wire nuts, jumpers, and other non-factory wiring visible in Figure 2. The compressor contactors had been switched to make compressor #1 activate with Stage-II and vice versa. The low-pressure safety switches were also reversed, which resulted in compressor #1 continuing to operate after a refrigerant leak, which ultimately resulted in compressor failure. Previous compressor replacements left too much oil in the system, and along with the compressor burnout, required that the system be flushed.

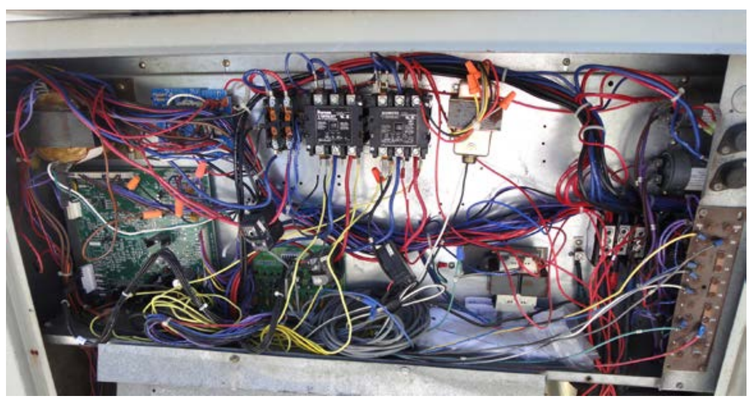

Figure 2 *Electrical / controls wiring in deviated from original.*

The total cost of the service and repair items related to deferred, improper or neglected maintenance was $14,348 not including the condenser fan motor replacements covered by the base O&M budget and further modifications to the unit beyond baseline. As a result of the refurbishment work, the field-measured integrated energy efficiency ratio (IEER) of the unit was improved from 7.8 to 9.5 [27]. This 22% performance improvement amounts to energy savings of $1,870 per year for this unit alone, and there are ten similar units on Building 1283. Further improvement to approach the factory rated IEER 11.2 would require replacement of the condenser coil and possibly the other compressor, which was deemed not cost effective. At IEER 9.5 the unit was operating 11% below its factory rating, which is typical considering the unit has been in service for 9 years and has an expected life of 12 to 15 years. The repair work will result in a total energy savings of $11,220 over the 6 remaining service years for this unit.

[27] Field measurement accuracy of change in IEER was calculated to be ±0.6 IEER points.

IMPACTS

In hindsight, comprehensive preventive maintenance for the 9 years since the installation of RTU-2 in 2003 would have cost approximately $7,200 for servicing twice per year at around $800 per year. Assuming linear straight-line deterioration in performance over 9 years, the added energy cost of deferring maintenance on this RTU was approximately $8,400. If the unit were allowed to continue to deteriorate to 12 years of service, the added energy cost would have been about $15,000 and unit life would likely have been 3 years shorter. Clearly, the cost of thorough twice-per-year preventative maintenance would pay for itself, with an over 50% return on investment, when the life-cycle cost of the unit is considered.

The actual energy efficiency of a unit that's been in operation for several years could be reduced 10% to 40% from its like-new condition, although it might appear to be 'running fine' to occupants. The reality is that many cooling units in service at DoD facilities are at times operating at poor efficiency levels. In FY 2011, DoD spent $4.1 billion on facility energy, which included $3.9 billion to power, heat and cool buildings. Making the following assumptions,

- 40% of the $3.9 billion is HVAC energy use
  - half of HVAC energy use is unitary equipment
    - two-thirds of unitary HVAC energy use is for cooling,

a reasonable estimate of air conditioning energy costs is $0.5 billion for DoD facilities unitary cooling equipment, which includes rooftop package units and split systems.

There are about 62,500 permanent actively used DoD buildings in the U.S. Among these buildings, there are 42,438 buildings (68%) that are smaller than 8,000 ft^2. Most of the small buildings are garage, ammunition, flammable storage and residential houses – of these, the buildings that are conditioned are likely to be cooled by unitary equipment (not including window units). There are 9,830 mid-sized buildings that are between 8,000 and 20,000 ft^2, which are also likely to be cooled by unitary equipment. In total, it is estimated there are approximately 20,000 DoD buildings in the U.S. that are cooled by unitary equipment. Assuming an average building size of 14,000 square feet with 23 tons of cooling, a $25 million preventive maintenance program would return approximately $50 to $100 million in annual energy savings, longer equipment life, and fewer unplanned cooling outages.

In FY 2011, DoD spent $15.1 billion on operational energy. Making the following assumptions,

- 40% of the $15.1 billion is fuel for operations electricity generation
  - 75% of electricity generation is for portable / field HVAC demand
    - equipment load factor averages 0.65
      - two-thirds HVAC energy use is for cooling,

a reasonable estimate of air conditioning energy costs is $1.9 billion for operational unitary cooling equipment, which includes field deployed package units and portable environmental control units (ECUs). Note that although operational cooling energy consumption is less than facility cooling use, the cost of energy in operations is much greater. There are approximately

15,000 MIL-STD ECUs fielded in extreme operational environments. Estimation of field maintenance costs is outside the scope of this paper.

In addition to the energy and repair costs associated with deferred RTU maintenance, the impacts include the liability deferred maintenance represents. Component breakdowns, system failures and unit shutdowns, classically at the most inopportune times, become more common. Not only are systems at risk for damage, building contents and people might be at increased risk as well, and maintenance staff productivity suffers. Assuming there are no emergency funds available, the financial impact of an occurrence/failure that must be fixed right away is typically borne by an O&M budget. O&M budgets are usually designed to provide for the ongoing routine service and minor maintenance needs not major, corrective maintenance projects.

Occurrences/failures resulting from deferred maintenance can put tremendous financial pressure on an O&M budget; a single unplanned air-conditioning outage can cost thousands of dollars and divert maintenance staff from their scheduled duties. Such occurrences typically lead to further reductions in preventive maintenance that are provided by the O&M staff and budget. Often and understandably, preventive maintenance activities are eliminated to make room for non-scheduled, unfunded, corrective maintenance projects that require immediate attention. A sustained reduction in preventative maintenance ends in a snowball effect that is the accelerated deterioration of the RTU, an increase in the maintenance needed, and subsequent increase in deferred maintenance. Clearly, O&M budgets are not satisfactory funding sources for the realized liabilities of deferred maintenance.

RECOMMENDATIONS

When faced with an urgent need to repair a failed air-conditioning unit, most facilities managers understandably choose to apply O&M funds to carry out the needed work. A financial mitigation strategy is to uphold separate O&M budget pools for (a) scheduled proactive preventive maintenance versus (b) contingency funds for unplanned / emergency repair of packaged air-conditioning equipment.

It is worthwhile to carry out and verify a preventive maintenance protocol on each package unit according to the size and age of the unit. Larger, newer units should receive more comprehensive attention to maximize sustainability and long term savings. Smaller units nearing the end of their lifespan have the least savings potential. The findings detailed above indicate energy savings from preventive maintenance are $50 to $100 per ton per year, so allocating at least $25 to $75 per ton annually for preventive maintenance would seem to be a reasonable guideline for DoD facilities' package and split system unitary equipment.

Figure 3 *Location of service items on RTU-2.*

The most critical preventive maintenance service actions in order are: cleaning the condenser coil, verifying operation of the condenser fan(s), adjusting refrigerant charge, checking compressor discharge temperature, testing the compressor oil for the presence of acid, testing high- and low-pressure cutout switches, adjusting the thermostatic expansion valve, verifying proper economizer operation, installing new MERV-6 rated or better filters, checking thermostat setpoints and scheduling, cleaning the evaporator coil, checking and adjusting the blower belt, lubricating the blower bearings, checking contactors, sealing cabinet and curb air leaks, and cleaning the blower wheel. A competent technician will work at the unit for 4 to 5 hours to complete a comprehensive annual service including all of these items at the onset of the cooling season. The higher priority items should be performed again near the end of the cooling season in 3 to 4 hours of at unit technician time. A prioritized checklist is provided at the end of this paper.

There exists in the air conditioning service industry, as in every other industry, different levels of service quality. It is worthwhile for DoD to seek out the highest quality companies, and they should be exclusively employed for preventive maintenance of unitary air-conditioning systems. In general, annual tune-ups are not profit makers for service contractors. The bulk of most contractors' profits come from installing replacement parts and replacement air conditioning units. Within even high quality companies, there exists a wide range of service technician experience and training. The maintenance results described in this paper call for highly experienced, well trained, factory certified technicians – the best of the best. Low quality service at low prices is not the least expensive.

Preventative maintenance should be scheduled before the onset of the cooling season, and again at the end of the cooling season. Top service personnel are typically busy diagnosing emergency problems and performing urgent repairs mid-summer. It is difficult to implement proper service under the pressure of having several emergency calls waiting for their arrival – proper preventive maintenance cannot be rushed.

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AIR-CONDITIONING ENERGY CHECKLIST FOR PREVENTIVE MAINTENANCE

Twice each Year

- Clean condenser coil with mild non-acid water-based cleaning solution.
- Straighten bent or smashed condenser coil fins.
- Verify proper operation of condenser fans.
- Test economizer / fresh air controls and damper operation. Cycle from full open to full close and back. Verify that fresh air dampers close during the unoccupied control mode.
- Inspect air filters and replace with MERV-6 or better filters if needed
- Review thermostat / controls / programming for correct operation. Check thermostat calibration against certified handheld electronic thermometer.
- Check refrigerant pressures and subcool / superheat temperatures. Adjust to optimum charge level. Inspect site glass for bubbles and moisture indication. If charge is low, find refrigerant leak and repair.
- Check amperage draw of compressor and fans and compare with nameplate RLA and FLA. Verify proper service voltage with all compressors running.
- Adjust fan belt tension; replace cracked or frayed belts
- Thoroughly flush condensate pan and drain line
- Tighten all hardware, replace loose, missing or rusted fasteners.

Annual

- Clean evaporator coil with appropriate indoor-use non-acid non-toxic water-based cleaning solution. Flush opposite direction of airflow, rinse thoroughly with fresh water.
- Inspect condensate drain, pan, pump, auxiliary pan. Clean entire drain system.
- Clean blower wheels and wipe cabinet interior, motors, and other hardware.
- Clean air intake screens and metal filters. Replace damaged filters.
- Inspect / replace fresh air damper / economizer gaskets and seals.
- Grease or oil fans, bearings and motors.
- Lubricate damper actuator linkages.
- Inspect, repair, and seal duct connections and adjust air dampers.
- Inspect cabinet seals and repair / replace if torn or smashed.
- Adjust or repair panels for airtight fit around equipment access openings.
- Check / tighten electrical power, contactor, control wire and tubing connections.

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